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COST BENEFIT ASSESSMENT OF CANDIDATE DECISION AIDS FOR NAVAL AI--ETC(U)

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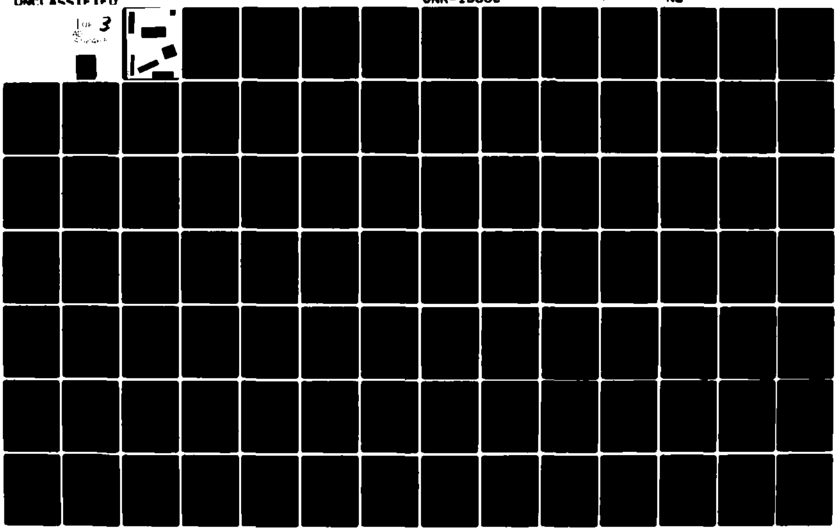

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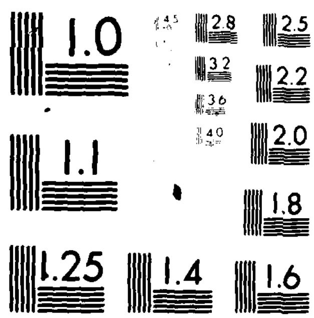

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Final Report
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COST BENEFIT ASSESSMENT OF CANDIDATE DECISION AIDS FOR NAVAL AIR ASW

30 September 1981

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

General methodologies are developed for assessing potential benefits and costs of candidate (early design stage) decision aids. Two types of decision aiding benefits are considered -- increases in mission achievement, and decreases in operator workload. The methodology assess both benefits across a range of related scenarios. Cost assessment considers total costs of developing, implementing, and maintaining an aid as well as savings, e.g., removal of equipment superseded by the aid, simplification of training procedures. Net costs are computed by subtracting savings from total costs.

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The benefit assessment methodology is applied to two candidate decision aids for the Naval Air ASW Tactical Coordinator (TACCO). One, the Sonobuoy Pattern Planning Decision Aid, helps the TACCO utilize in-situ environmental conditions and intelligence updates during selection of sonobuoy search pattern. The other, the Attack Planning Decision Aid, helps the TACCO obtain attack criteria and place an optimal attack. Both aids produce substantial increases in mission achievement. The Sonobuoy Pattern Planning aid yields a moderate decrease in operator workload, while the Attack Planning aid yields a more sizable decrease in operator workload. Further development of both aids is deemed justifiable, and a detailed man-machine interface for the Sonobuoy Pattern Planning Aid is presented.

ACKNOWLEDGEMENTS

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1. INTRODUCTION AND OVERVIEW

Recent years have seen a rapid and substantial increase in the technological sophistication of Naval Air ASW operations. Along with this increasing hardware sophistication have come demands for increasingly rapid and accurate decision-making on the part of ASW aircrews, making Air ASW a prime candidate for application of decision-aiding techniques. This report covers the current Analytics research effort to develop decision aids for Naval Air ASW. The effort described here focuses on generating and applying methods to assess the benefits that could be expected and the costs that would accrue from implementing Air ASW decision aids designed in previous efforts.

There have been four major phases to Analytics' research (see Zachary [1980a, 1980b]) into ASW decision aiding:

1. Definition of critical decision points in the Air ASW mission at which decision aiding could be applied,
2. Identification of decision aiding techniques applicable to each of these decision situations,
3. Prioritization of the decision situations according to their criticality to the overall ASW mission, and
4. Assessment of the potential benefits that could result from specific decision aids for two high priority decision situations.

Each of these is briefly reviewed below as background for the remainder of this report.

1.1 REVIEW OF PREVIOUS RESEARCH

This research program began with an analysis of the commonalities among the missions flown by the principal ASW platforms for the 1980-1985 timeframe

(P-3C, and S-3A, and LAMPS MK III). That analysis resulted in the construction ofa generic Air ASW mission profile, from which the various decisions made during the mission flight by the Tactical Coordinator (TACCO) were identified and investigated. The TACCO was made the central focus of the investigation because it is the explicit function of the TACCO to coordinate the decisions and efforts of the other crewmembers into a tactical plan of action to achieve the mission objectives. The mission analysis showed that the TACCO makes similar decisions throughout the Air ASW mission, but toward different ends depending on the particular objective or goal event of the current mission phase. For example, the TACCO makes sonobuoy placement decisions throughout the mission, but uses different criteria in the On-Station Search portion of the mission where the goal event is gaining contact with a hostile submarine, than during the Attack Planning portion of the mission where the goal event is the placing of an attack on the submarine. The differing goal events for the mission phases give rise to complex decision-making contexts, which constrain the ways in which the TACCO's primary decision functions are carried out. These contexts, termed *decision-making situations*, were identified as the principal units to which decision aiding should be applied. The six decision situations thus defined are listed in Table 1-1, along with their goal events.

Table 1-1. ASW Decision Situations and Goal Events

DECISION SITUATION	GOAL EVENT
ON-STATION SEARCH	GAIN CONTACT WITH TARGET OF INTEREST
CONTACT CLASSIFICATION/VERIFICATION	IDENTIFY SOURCE OF CONTACT
LOCALIZATION	DETERMINE LOCATION, COURSE, SPEED AND DEPTH OF TARGET
SURVEILLANCE TRACKING	MAINTAIN LOCALIZED CONTACT WITH TARGET
ATTACK PLANNING	PLACE OPTIMAL ATTACK AGAINST HOSTILE TARGET
LOST CONTACT REACQUISITION	REGAIN AND LOCALIZE CONTACT WITH A LOST TARGET

Existing decision aids were then reviewed and analyzed to determine the capabilities and characteristics of current decision-aiding technology. Complete existing decision aids were found to be highly specialized, and not directly applicable to any of the identified ASW decision situations. These existing decision aids, however, were also found to be constructed from similar constituent decision-aiding techniques, which were extremely general. Subsequent analysis of the functions these individual techniques performed in the various aids showed there were many fewer functional categories of techniques than techniques themselves; these categories were formalized, then employed to group the techniques into a functional taxonomy of decision-aiding methods. The highest-level categories in the taxonomy were used as the basis of a descriptive framework which permits decision situations to be described so that specific relevant decision aiding techniques can be identified and matched with specific aspects of the situation. This matching methodology was applied to the six ASW decision situations, resulting in an identification of the possible combinations of aiding techniques appropriate for each situation.

Having thus identified the potential applications of decision aiding in Naval Air ASW, it was then necessary to determine their relative priority, so that development of actual decision aids could begin with the highest priority problems. A preliminary attempt at a purely analytic (i.e. non-experimental) prioritization pointed out the need to treat priority as a multidimensional measure, and the need to incorporate the judgments of experienced operational ASW personnel into the prioritization procedure. To that end, a prioritization technique called Priority Mapping was developed and applied to the six Naval Air ASW decision situations identified previously. Priority Mapping uses Multidimensional Scaling and Unfolding Analysis to translate TACCOs' nonquantitative judgments about the similarity among and ranked importance of decision functions they perform into numerical priority scores for the decision situations in which these decision functions arise.

In Priority Mapping, judgmental data on the perceived similarities among a set of decisions are preprocessed (with a computer program entitled METRIC) to obtain numerical measures of the pairwise dissimilarity of these decisions. The method of Multi-Dimensional Scaling (MDS) is then applied to this measure of dissimilarity to uncover the principles, or dimensions, that underlie the decisions considered. In MDS, the decisions are represented as points in a multidimensional space -- the precise number of dimensions in the space must be determined as part of the 'solution' -- with each dimensional axis representing a fundamental feature or principle which interrelates the decisions.

Another technique, called Unfolding Analysis, is then applied to the data on the ranked importance of the decisions and the multidimensional scaling solution to determine the mathematical form of the implicit priority functions used by the TACCOs to rank the decisions. Unfolding Analysis works by seeking a 'reference point' in the multidimensional space and a distance metric (formula for computing interpoint distances) such that the order of the distances of the decisions in the space from the reference point replicates the rank orderings (by importance) given by the TACCOs. When such a reference point and metric are found, the distances of the decisions from the reference point give the decisions' numerical priority scores. This final calculation of the priority scores (from the distance metric and the reference point) is performed by a program called PREFMAP. The overall prioritization methodology, as applied to Naval Air ASW, is summarized in Figure 1-1. Priority scores for the individual decisions are then combined across decision situations in which the individual decisions are embedded, to create a prioritization of the decision situation.

Priority Mapping was initially applied to data collected from 32 highly experienced TACCOs stationed at NAS Moffett Field, California, and yielded the decision situation prioritizations shown in Table 1-2. Separate prioritizations were needed for Attack and Surveillance Missions because the TACCOs felt that the priority of a decision depended on the type of mission in which it was made. A subsequent reanalysis incorporating additional data collected by the Navy and made available to Analytics has completely replicated these results, and a separate, parallel study (see Cagel, 1980) using S-3A TACCOs has produced similar conclusions.

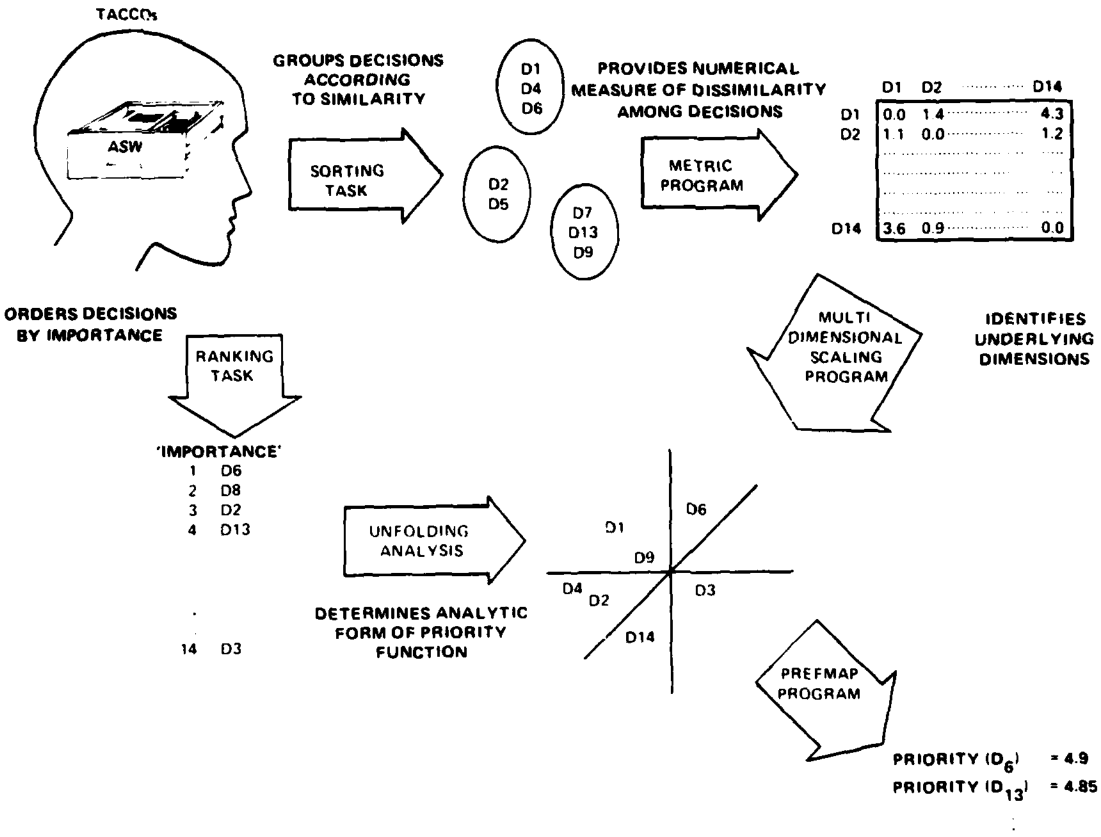

Figure 1-1. Priority Mapping Procedure for Prioritizing Naval Air ASW Decisions

Table 1-2. ASW Decision Situation Prioritizations in Two Types of ASW Missions

RANK IN MISSION WITH ATTACK OBJECTIVE	DECISION SITUATION	DECISION SITUATION	RANK IN MISSION SURVEILLANCE OBJECTIVE
1	CONTACT CLASSIFICATION/ VERIFICATION	CONTACT CLASSIFICATION/ VERIFICATION	1
2	ATTACK PLANNING	SURVEILLANCE TRACKING	2
3	LOCALIZATION	LOST CONTACT REACQUISITION	3
4	SURVEILLANCE TRACKING	LOCALIZATION	4
5	LOST CONTACT REACQUISITION	ON-STATION SEARCH	5
6	ON-STATION SEARCH	ATTACK PLANNING	6

1.2 ASSESSING THE POTENTIAL BENEFITS AND COSTS OF CANDIDATE DECISION AIDS

Based on the results of the priority mapping analysis, high-level designs for two Air ASW decision aids were constructed. Designs were developed for the decision situations showing the highest priority (Attack Planning and Contact Classification/Verification). The high-level design consists of *functional specifications* of the aid's performance requirements (i.e., specifications of what functions the aid would perform) and general *technical specifications* of the aid's algorithmic requirements (i.e., specifications of possible mixes, of decision-aiding techniques which could fulfill the performance requirements). Thus, these high-level designs provide information on *what* the aids would do, and *how* they would do it. In Zachary (1980b), designs for these two decision aids -- the Attack Planning decision aid and Optimal Processing Modes Selection decision aid -- are presented. Similar high-level designs for seven additional Air ASW decision aids were constructed in a separate effort and are presented in Kelley, Ousey, and Zachary (1981).

1.3 DECISION-SITUATION AIDABILITY AND DECISION-AID DEVELOPMENT

The Priority Mapping procedure prioritized the six Air ASW decision situations for decision-aid development and the subsequent creation of the high-level decision-aid designs initiated this development process. On the surface, it would seem that full development of one or more decision aids should be undertaken first for those situations showing highest priority for aid development. However, high priority is not by itself a sufficient condition to warrant full decision-aid development. Before an aid's construction is completely justified, it must also be shown that the decision aid will have a demonstrable and positive payoff to Naval Air ASW operations. Thus, the justification for the development of an aid must be based on two factors: the importance of the situation being aided, and the degree to which decision making in that situation is "aidable" by the candidate decision aid. It is this second factor, the *aidability* of the situation by the candidate aid, that is considered in this report.

The aidability of a decision situation by a candidate decision aid can be assessed by measuring the potential costs and benefits to be expected from the aid. The remaining sections of this report document procedures to assess the costs and benefits of candidate decision aids. Although these procedures focus on Air ASW decision aids and are applied to two of the Air ASW decision aid designs previously constructed, they are nevertheless quite general and could, with straightforward modification, be applied to any type of decision aid. Section 2 (Methodology for Benefit Assessment of Candidate Decision Aids) introduces a comprehensive and general method for measuring the specific benefits that can be expected by the introduction of a given decision-aiding system. The method considers both *direct* benefits (in the form of increases in levels of mission achievement), and *indirect* benefits (in the form of decreases in levels of operator workload). Section 3 (Methodology for Cost Assessment of Candidate Decision Aids) introduces an analogous general method for determining the specific costs that can be expected to arise from the development, implementation, and operation of a given decision-aiding system. This method considers both the overall *costs* (e.g., cost of research and development, acquisition and implementation, and maintenance) as well as the overall *savings* (e.g., saving from the elimination of equipment and procedures superceded by the decision aid) in yielding a unit-level net economic cost of the proposed decision-aiding system.

The next two sections of the report concern the application of the benefit assessment methodology to two high-priority decision aids. These are the aid for Attack Planning (as initially described in Zachary [1980b], and reviewed in Subsection 5.1 below), and the aid for Sonobuoy Pattern Planning (as initially described in Kelley *et al.* [1981], and reviewed in Subsection 4.1 below). The benefit assessment of the Sonobuoy Pattern Planning aid is described in Section 4, and the benefit assessment of the Attack Planning aid is described in Section 5. Both aids are determined to show substantial benefits, with the Sonobuoy Pattern Planning aid promising high gains in Mission Achievement and the Attack Planning aid promising both substantial reductions in Operator Workload and large gains in Mission Achievement.

Based on the results of these benefit analyses, it is concluded that further development of both aids is warranted. As a next step along the development path, Section 6 outlines in detail one possible man-computer interface for the Sonobuoy Pattern Planning decision aid. This section also provides some more general information on the constraints which any decision aid for Naval Air ASW must consider in its man-computer interface. Finally, Section 7 provides a series of conclusions from the research reported here, along with recommendations for future research in this area.

2. BENEFIT ASSESSMENT OF CANDIDATE AIR ASW DECISION AIDS

One of the most basic continuing concerns in decision-aiding research is the establishment of systematic, generalized methods to guide the process of designing and engineering decision-aid systems. The previous phases of this program (as described in Subsection 1.1) have developed such general methods for:

- identifying the decision-making situations within a tactical domain where decision aiding is needed,
- selecting the appropriate decision-aiding techniques to enhance decision making in these situations, and
- prioritizing decision-making situations for decision-aid development.

The application of these methods to Naval Air ASW has resulted in the creation of high-level decision-aid designs for two high-priority Air ASW decision situations. It might therefore seem that with the establishment of those methods and the creation of these decision-aid designs a complete methodology has been both developed and applied but this is not the case. Although the priority of a decision situation is an important consideration in determining where to apply decision-aiding technology in a given tactical domain, it is not the only consideration. There is another equally important issue which must also be addressed -- the degree to which the high-priority decision situation is amenable to aiding by the candidate decision aid design. This issue can be termed the "aidability" issue, and is one of the most important issues still unaddressed in decision-aid research.

In its most basic form the aidability question can be expressed as a simple trade-off between the potential costs and benefits that would result from applying a candidate decision aid to a specific decision situation. A candidate decision aid (i.e., one specified only by a high-level design) would if implemented, yield certain direct and indirect increases in decision-making performance which could be termed its *benefits*. At the same time the development, implementation, and operation of the aid would also result in certain *costs* as well. The aidability of the decision situation by that aid can then be seen as the degree to which the aid's potential benefits offset its potential costs.

This section presents a methodology for assessing the potential benefits that a decision aid specified only by high-level design would yield if it were fully developed and implemented in its intended tactical environment. Section 3 presents an analogous methodology for assessing the potential costs of a candidate decision aid. Although the overall structure of the benefit assessment discussed below is of general applicability, it is presented within the framework of assessing decision aids for Naval Air ASW. This is done to fully specify the methodology that was used in assessing the potential benefits of two specific candidate decision aids for Naval Air ASW -- the Sonobuoy Pattern Planning decision aid and the Attack Planning decision aid. The application of this methodology and the results of the benefit assessments of these two aids are discussed in Sections 4 and 5 (respectively).

2.1 STRUCTURE OF THE METHODOLOGY FOR DECISION AID BENEFIT ASSESSMENT

Before a methodology for assessing the benefits of a decision aid can be constructed, it is first necessary to determine precisely what types of benefits a decision aid may yield. The best way to do this is to relate the aid's use to the overall objectives of the situation in which this use would take place. A military decision aid's benefit can therefore be assessed in terms of the ways the aid contributes to the maximization of mission achievement. Since a mission may have multiple objectives, there can be several ways in which a decision aid can increase the level of mission achievement.

There are two general classes of mission-achievement decision-aiding benefits. The first can be termed direct benefits. The implicit premise underlying decision aiding is that the quality of decisions made during a mission directly affect the outcome of the mission and that consequently any improvement in decision-making quality will yield in a concomitant improvement in the level of mission achievement. By this premise, decision aids can *directly* increase mission achievement simply by leading to better decisions.

Second, a decision aid can contribute to increased mission achievement indirectly by reducing the overall workload of the human decision maker. Many, if not most of today's military systems are characterized by a high degree of technological sophistication. They contain many complex subsystems, require a high degree of manual and cognitive skill to operate, and require inputs and responses from their human operators in such short timeframes as to sorely tax the operators' ability to perform. Naval Air ASW platforms are prime examples of this trend. Moreover, because many subsystems of such complex systems operate concurrently the system operators of these systems often find themselves performing several tasks simultaneously. This has resulted in a crisis in workload, as pilots, tactical flight officers, etc., increasingly find themselves without sufficient time to perform all of their assigned tasks. Although data on human performance of simultaneous complex tasks are lacking, it is intuitively clear that the reduction of operator workload on one task will result in an improvement in performance on other tasks by freeing mental resources for them. Thus, if a decision aid can simplify the operator's procedures in a given decision task, it will free him to devote more time and attention to other concurrent decision tasks and as a result improve his performance on those tasks, even though they are not directly addressed by the aid. Therefore, by reducing levels of operator workload, a decision aid may *indirectly* lead to increases in the levels of mission achievement.

A methodology for assessing decision-aid benefits must consider both direct benefits via higher quality decisions, and indirect benefits via reduction of operator workload. It must also consider the wide range of mission conditions under which the decision aid might be used and which might influence the decision-making process. The evaluation of a specific mission is affected by a number of contingencies, each of which differentially affect the benefits that would result from the use of the aid in that mission. This suggests that a decision aid should not be assessed within a *single* scenario (as is, for example, customarily the case in workload analysis), but across a *range* of scenarios which spans the full gamut of factors that can affect the decision(s) being aided.

A logical approach to assessing decision-aid benefits is to consider direct and indirect benefits separately. Direct benefits can be assessed in four general steps. First, a group of scenarios which represent the various factors and conditions affecting the decision involved is constructed. Second, the quality of decision making in the current (i.e., unaided) condition is quantitatively measured or estimated for each of these scenarios. Third, the quality of aided decision making is quantitatively measured or estimated again for each of the scenarios. And, fourth, quantitative comparisons of aided and unaided decision quality are made and averaged across the range of scenarios considered. This yields a measure of expected change in decision quality, across the range of conditions under which the decision is likely to be made.

The indirect benefits are assessed in an analogous four-step procedure. As with direct benefits, the first step in indirect benefit assessment is the construction of a set of mission scenarios which include all major contingencies affecting the performance of the decision task involved. Second, the operator procedures involved in making the decision in the current (i.e., unaided) condition are identified, formalized, and quantitatively measured or estimated for each scenario. Third, the procedures the operator would use to make that decision *with the decision aid* are determined and formalized and quantitatively measured or estimated for each scenario. Fourth, the operator workload measures for the aided condition are quantitatively compared to those for the unaided conditions, and averaged across the range of scenarios used. This results in a measure of change in operator workload that is adjusted for the full range of conditions under which the decision tasks are performed.

A methodology for carrying out these benefit assessment procedures for candidate Naval Air ASW decision aids is shown in Figure 2-1. This methodology begins with a candidate decision aid design, as shown at the top of the figure. Four other types of supporting data are required at the outset. These are:

- Detailed data on ASW procedures and tactics,
- Detailed data on the capabilities and characteristics of the existing avionics system of the ASW aircraft,
- Knowledge of the "real-world" contingencies which affect the decision addressed by the candidate decision aid, and
- Information on the detailed aspects of the Naval Air ASW missions.

The knowledge of the contingencies which affect decision making in the operational ASW arena (i.e., the "real-world") is used to construct a set of scenarios to assess the aid's potential benefits. A convenient way of approaching this scenario-building process is to initially define a single scenario in which all aspects are fixed except those directly relating to one of the identified contingencies. This "core" of a scenario is then allowed to evolve along different paths by choosing a small number of representative variations of this contingency; each identified contingency is treated in the same manner. The result of this process is a *scenario tree* -- a set of scenarios with the same core but which also spans a substantial range of the relevant mission contingencies. Some of the advantages of this approach are discussed in Subsection 2.2 below. Also used in constructing the scenario tree is the information on Naval Air ASW missions. This data is used to ensure that the objectives of the mission in the scenario are in keeping with the actual Air ASW mission, and are appropriate for the benefit assessment of the decision aid.

The data on ASW tactics and procedures and on the ASW aircraft avionics system are used to identify the procedures currently employed to make the decision addressed by the decision aid. These unaided operator decision procedures are then combined with the decision-aid design and the relevant ASW

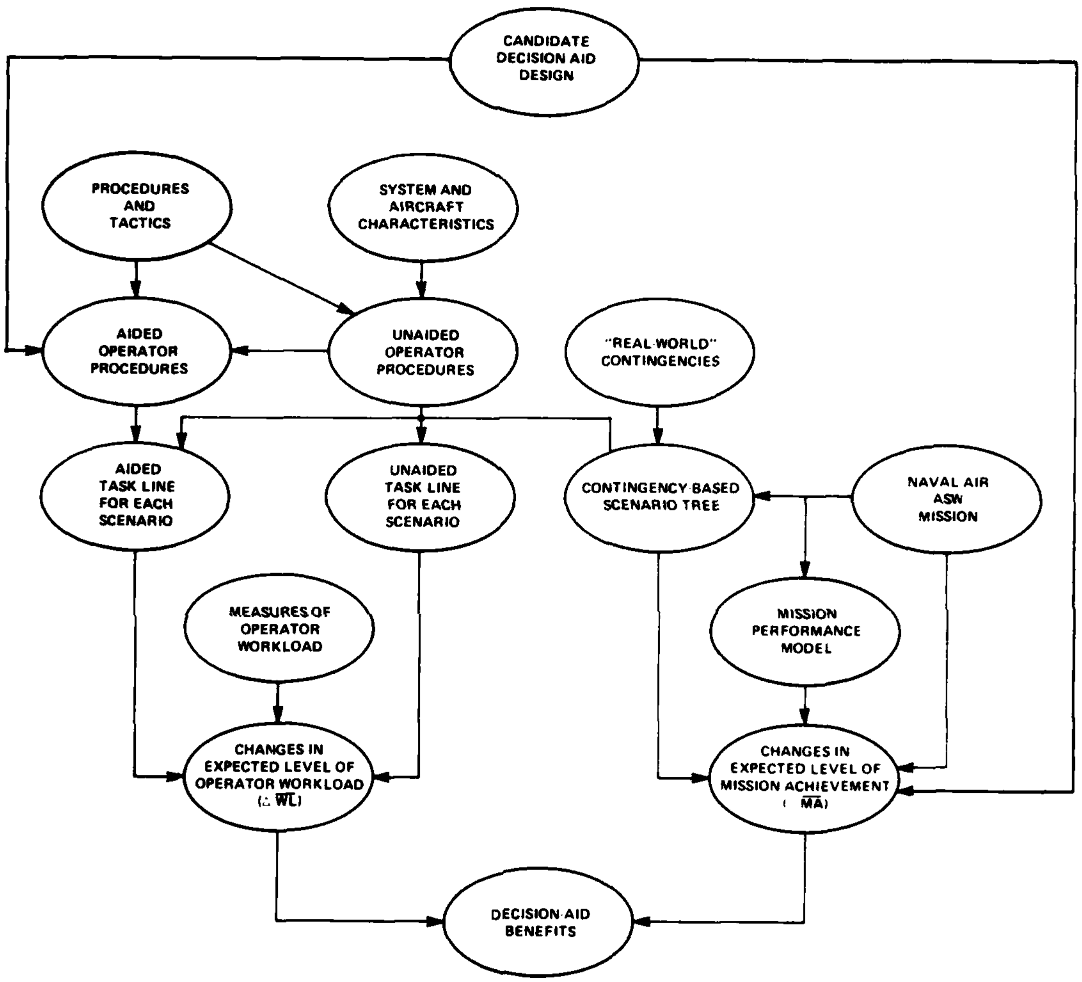

Figure 2-1. Methodology for Benefit Assessment of Candidate Decision Aids

tactics to define the decision procedure the operator would perform if the decision aid were implemented, i.e., the aided operator procedures.

The definition of these aided and unaided decision procedures is the first step in the assessment of the decision aid's indirect benefits. Both the aided and unaided operator procedures are then formalized so that they can later be subjected to quantitative workload measurement techniques. Next, these formalized procedures are combined with the scenario tree to produce a detailed "taskline" of the actions (both mental and physical) required to make the decision in each specific scenario. This taskline is structured as a timeline, but identifies the specific operator tasks that must be accomplished at each point in time, as well as the specific functions which must be initiated and/or completed.

Measures or scales of operator workload are then applied to each of these tasklines to produce a quantitative index of operator decision-making workload during each scenario in both the aided and the unaided condition. These indices are compared for each scenario and combined across scenarios by summing the aided/unaided index ratios, after weighting each by the estimated probability of each scenario obtaining in the real world. The resulting value then gives the expected reduction in operator workload from the aided to the unaided condition, or $\Delta\overline{WL}$, as indicated in Figure 2-1. The calculation of $\Delta\overline{WL}$ is discussed in more detail in Subsection 2.2 below.

The direct benefits are assessed in an analogous manner. Using the knowledge of the Naval Air ASW mission, a model of the relationship between the quality of the decision addressed by the aid and overall mission achievement is constructed. This model can be a mathematical model, a statistical model, or computational model; its function is simply to relate a given decision to the objectives of the mission. For example, a sonobuoy pattern selection decision results in the choice of a specific sonobuoy pattern for deployment; in order to assess the quality of this decision, this specific selection must be related to the objectives of the appropriate mission phase. This is done by the mission achievement model; if the pattern is deployed in the On-Station Search portion of the mission, the model calculates the probability of detecting the submarine with this pattern.

The mission achievement model is first used together with the scenario tree to measure the quality of the unaided decisions in each scenario of the scenario tree. It is then used to measure the quality of the aided decisions in the same scenarios. The aided and unaided mission achievement values are then compared for each scenario and combined across scenarios in the same fashion as the operator workload indices, resulting in a measure of changes in the expected level of mission achievement from the aided to the unaided condition, or $\Delta \overline{MA}$. The calculation of $\Delta \overline{MA}$ is elaborated in Subsection 2.2.

The remaining subsections of this section provide additional details of the benefit assessment methodology shown in Figure 2-1. Subsection 2.2 discusses the identification of mission contingencies and the construction of scenario trees for decision-aid benefit assessment. Subsection 2.3 discusses the calculation of mission achievement benefits. Subsection 2.4 presents methods for capturing and formalizing aided and unaided operator decision procedures, Subsection 2.5 considers the measurement of operator workload and the calculation of operator workload reduction benefits.

2.2 MISSION CONTINGENCIES AND SCENARIO TREES

Each event or occurrence that is not part of a given decision but which nonetheless affects it can be termed a contingency upon which that decision depends. Every tactical decision is affected by a variety of mission contingencies. For example, the number of options available in a given instance of a decision may depend upon the resources available at that point in the mission; the prior mission events which affect the availability of resources at the time this decision is made are thus contingencies which affect it. In assessing the potential benefits of a decision aid, it is important to consider the aid's utility across a wide range of potentially obtainable conditions. Therefore, it is necessary to identify all the major mission contingencies which may affect the decision being aided and to compare aided and unaided decision making under all the various combinations of outcomes resulting from these contingencies.

The simplest way of doing this is through the construction of a scenario tree for the decision aid assessment procedure. A scenario tree is a generalized mission scenario which evolves along different but related paths created by differential outcomes of specific contingencies at predefined points in the mission timeline. The concept is best explained in the context of a hypothetical example. Suppose that a certain ASW decision (for which a decision aid is being assessed) is determined to be affected by two contingencies: the number of sonobuoys available at the point in the mission at which the decision is made, and the accuracy of the environmental predictions given to the aircraft at its preflight briefing. A scenario tree is built around these contingencies as follows. First, a general Air ASW scenario is constructed in which all factors but the accuracy of the environmental predictions and the events which affect sonobuoy availability are fixed. Then, mission times are identified at which factors affecting these two contingencies come into play. For environmental predictions, the relevant time is shortly after the ASW aircraft arrives on station and deploys its environmental recording sonobuoys. The data recorded by these sonobuoys will either validate or refute the environmental predictions. The mission is then determined to have two general evolutions from this point. In one case the environmental recordings indicate that the predictions are accurate, and in the other indicate that the preflight predictions are incorrect. For sonobuoy availability, a critical point in the mission might occur during the prosecution of an initial contact with the submarine. A loss of contact could lead to the utilization of a substantial number of sonobuoys (not otherwise used) during the lost contact reacquisition procedures. Therefore, each of the two mission evolutions possible at this point are themselves determined to have two possible subsequent evolutions. In one case, the prosecution proceeds smoothly and only ten sonobuoys are utilized prior to the decision of interest, while in the other case, the contact is lost and an additional 20 sonobuoys are required to regain the contact. This example considers a relatively simple scenario tree in which there are only four "leaves" or distinct evolutions, but it serves to demonstrate the scenario-tree construction process.

In general, a scenario tree for a given decision aid is constructed in four steps. First, the relevant mission contingencies are identified. Second, a general scenario is constructed in which all factors except those relating to the identified contingencies are fixed. Third, points are identified at which differential outcomes involving the identified contingencies occur. And fourth, the scenario is allowed to take different evolutions at each of these points, with each distinct evolution reflecting a different possible combination of outcomes of the contingent events. In this way, a number of different evolutions or scenario tree leaves are created, each of which represents a unique combination of contingent conditions affecting the decision addressed by the decision aid.

There are two clear benefits of the scenario tree approach. The first is that it simplifies the benefit assessment procedure. Because all factors but those affecting the contingencies are fixed throughout the mission evolution, there are many commonalities among the different evolutions. This greatly simplifies the process of establishing parameters for the execution of mission performance models needed to calculate levels of aided and unaided mission achievement in each scenario leaf. It also simplifies the formalization of operator procedures, as most operator procedures other than those involved with the specific decision examined are the same across all leaves in the scenario tree.

The second benefit of the scenario tree approach is that it allows the probabilistic relationships among the various scenario evolutions to be established easily. Each contingent event (i.e., branch point) in the scenario tree can be considered as an independent event, and probabilities can be assigned to each branch on that basis. In the example given above, the initial branch point is deployment of the environmental sonobuoys. The probability (denoted P_1) that the environmental sonobuoys will validate the predicted conditions can be estimated from historical data and/or by expert opinion. This probability is then assigned to the corresponding branch of the scenario tree. The complementary probability (i.e., $1-P_1$) is then assigned to the other branch. This process is repeated for all branch points *independent* of each other. The overall probability of each unique scenario evolution occurring is then computed by multiplying all the probabilities on the branches of the path which represents that evolution.

This probabilistic analysis of the scenario tree provides a way of mathematically combining the comparisons of aided and unaided benefits (whether mission achievement gains or operator workload reductions) across all the scenarios. Each leaf in the scenario tree will ultimately have five values:

- P_i = the probability of that scenario evolution occurring,
- UMA_i = unaided mission achievement in that scenario evolution,
- AMA_i = aided mission achievement in that scenario evolution,
- UWL_i = unaided operator workload in that scenario evolution,
- AWL_i = aided operator workload in that scenario evolution.

These values are then combined according to the following formulae to yield expected level changes in mission achievement ($\Delta\overline{MA}$) and operator workload ($\Delta\overline{WL}$):

$$\Delta\overline{MA} = \sum_i P_i \left(\frac{AMA_i}{UMA_i}\right) \tag{2.1}$$

$$\Delta\overline{WL} = \frac{\sum_i P_i \, (AWL_i - UWL_i)}{\sum_i P_i \cdot UWL_i} \tag{2.2}$$

The formulae differ because the MA values are measured on a ratio-scale, while the WL values are measured on an interval scale. These formulae are used in Sections 4 and 5 below to determine the overall benefits of the Sonobuoy Pattern Planning and Attack Planning decision aids.

2.3 MISSION ACHIEVEMENT BENEFIT CALCULATION

Once the scenario tree for the benefit assessment procedure has been constructed, the calculation of mission achievement benefits can be directly undertaken. Since the purpose of the entire benefit assessment procedure is to determine the potential gains in mission achievement brought about by the introduction of the decision aid it is necessary to estimate these possible gains without a detailed knowledge of and/or access to the specific decision-aiding algorithm to be utilized. This suggests that the assessment of possible increases in mission achievement should concern itself not so much with the quality of the decision-aid algorithm as with the quality of unaided decision making. In specific, the focus should be on the room for improvement that currently exists in the unaided condition. If by making a more optimal decision than could be currently made a substantial increase in mission achievement would result, then it can be said that there is great room for improvement in unaided decision making. On the other hand, if by making a more optimal decision only an insignificant increase in mission achievement would result then it can be said that there is little room for improvement in unaided decision making. The benefit assessment of a candidate decision aid should determine whether or not there is sufficient room for improvement in unaided decision making as to warrant the development if any decision is made.

The actual calculation of unaided and aided mission achievement for a specific scenario evolution (i.e., of UMA_i and AMA_i) is accomplished in a five-step procedure. First, using the necessary data from tactical, technical, and system operation manuals, the decision that the operator would make without the aid in a specific scenario is identified. Second, a mathematical, simulation, or computational model is located (or built) and exercised to relate this unaided decision to the mission achievement criteria of the appropriate mission phase. If for example the decision arises in the Attack Planning portion of the Air ASW mission, then it should be somehow related to the probability of killing the submarine. If more than one criterion is relevant to the mission phase, then the model must relate the decision to each one of them.

Third, using the decision-aid design together with the relevant tactical manuals, the best decision that could be made *with the information available on-board the aircraft* is determined. This is considered to be the "aided" decision. This best or optimal decision is restricted to that which could be made with the information available on the aircraft to avoid the comparison of unaided decisions with "20/20 hindsight" decisions. For example, if the decision maker had perfect information on the target's location, then he could immediately place an attack on it with 1.0 probability of kill, but such information would, of course, never be available to him. However, if probabilistic data on the accuracy of sensor information could be gathered and used to improve the TACCO's knowledge of target location by 50 percent, then a decision based on a 50 percent better estimate of target location could be considered as the aided decision in this simplified case.

Once the aided decision is determined, the mission achievement model is again used to relate this decision to the relevant mission achievement criteria. This is the fourth step in the process. The fifth step is required only in cases where more than one mission achievement criterion is used. In this step, some combination rule is used to combine the various mission achievement values across criteria into a single figure for AMA_i or UMA_i. After all the AMA_i and UMA_i have been calculated, they are substituted into equation 2.1. above.

2.4 IDENTIFICATION AND FORMALIZATION OF OPERATOR PROCEDURES

The calculation of reductions in operator workload can also be initiated once the scenario tree for the decision-aid assessment procedure has been constructed. There are two major stages in the assessment workload reductions: (1) the formalization of operator tasks and (2) the measurement of the workload associated with these tasks. This subsection considers the first stage and the next subsection discusses the second stage.

Operator workload must be measured separately for both the aided and unaided conditions in each scenario evolution in the scenario tree. Before the actual measurement of operator workload can be undertaken, however, it is first necessary to identify the specific tasks which the operator undertakes in each scenario evolution and aiding condition and to formalize them in such a way that their associated workload can be quantitatively measured. This identification and formalization is accomplished in four steps.

In the first step, the general functions the operator performs during the mission phase in which the decision aid is used are identified. These functions are general in that they must be performed in all scenario evolutions with and without the decision aid. In the second step, two timelines (aided and unaided) are constructed for each scenario evolution in the scenario tree. Each timeline indicates the times at which the operator performs the general functions in that particular mission evolution and aiding condition. If certain functions are completely automated in the aided condition, then they are so indicated on the timeline and placed at approximately the point in time at which they would be performed by the decision aid.

In the third step, the general operator functions identified in the second step are decomposed into specific operator tasks and formalized. The vehicle used for this formalization is the HOPROC (for Human Operator Procedures) language for task analysis. HOPROC is a task-analytic language developed to describe complex sequences of operator tasks for simulation and analysis by HOS -- the Human Operator Simulator (see Strieb, Glenn, and Wherry, 1978). The great advantage of HOPROC over other task-analysis methods is that it allows even complex operator procedures to be expressed in readable, English-like statements which are non-ambiguous and concise. An even greater advantage of HOPROC is that it permits the description of operator tasks at a *logical* rather than *physical* level, and thus minimizes the extent to which specific details of the candidate decision aid design must be defined during the workload assessment procedure. HOPROC describes operator tasks simply by stating what the operator is attempting to logically accomplish, e.g., "Read information X," or "Move trackball to place cursor desired location." This level of description is logical because it does not require specification of physical characteristics of the task, such as the format in which information X is presented, the location where it is displayed or printed, or even whether X is displayed or printed. Thus, while it is still necessary to specify the candidate decision aid at some level of detail beyond the high-level design, the required level of detail is minimized. To create the needed HOPROC representations of operator procedures, it is sufficient simply to identify the logical tasks the operator must perform to fulfill the general function involved, and to describe the ways in which this might be accomplished with the aid.

A drawback of HOPROC for decision-aid benefit analysis, however, is that it is oriented toward analysis of manual tasks rather than cognitive ones (such as those involved in decision making).* In formalizing the operator procedures for this portion of the benefit analysis, it is therefore necessary to extend the syntax of HOPROC to include statements describing more of the cognitive aspects of the decision making than could be expressed in standard HOPROC alone.** Many of the syntactic conventions needed in HOPROC to facilitate its parsing and compilation by HOS are also excluded from this extended HOPROC, which is termed "pidgin-HOPROC" after the "pidgin-ALGOL" invented by Aho, Hopcroft, and Ullman (1974) for the analysis of computer algorithms.

From this third step two sequences of pidgin-HOPROC statements for each scenario evolution are produced -- one for the current (unaided) procedures and another for the procedures associated with the decision aid. These sequences may contain complex branching structures (e.g., IF-THEN-ELSE sequences) to represent the ways in which the operator would cope with different mission contingencies. However, in any given scenario evolution, each mission contingency has a specific outcome; therefore all branches but one in the HOPROC sequence become superfluous in any given scenario evolution on the scenario tree. Thus in the fourth step, the pidgin-HOPROC sequences are combined with the

*A more thorough discussion of the advantages and drawbacks of using HOPROC in decision-aid assessment can be found in Zaklad (1981).

**The need to resort to this language extension precludes the use of HOS to measure operator workload.

scenario-specific timelines and the scenario tree to produce two HOPROC tasklines for each scenario evolution. These tasklines contain only those pidgin-HOPROC statements needed to represent the actions the operator would actually undertake to accomplish each function in that specific scenario evolution. In constructing these tasklines, the sequences of pidgin-HOPROC statements representing each operator function are combined by placing them at the times at which the functions are performed on the timeline for the scenario evolution/aiding condition involved. In this way, a unique sequence of pidgin-HOPROC statements is generated for each scenario evolution and aiding condition. Each statement in a sequence represents a specific, well-defined operator action whose associated workload can then be measured by an appropriate workload measurement procedure.

2.5 MEASUREMENT OF OPERATOR WORKLOAD

The measurement of operator workload is one of the most fundamental issues in human factors research, and there have been almost as many methods defined as researchers examining the problem. However, of the four general approaches to workload measurement identified by Wierwille and Williges (1978) --direct or primary task measurement, indirect or secondary task measurement, subjective ratings, and model-derived estimation-- only subjective ratings and model-derived estimation are appropriate for the type of benefit assessment considered here. This is because direct and indirect measurements methods can be applied only to real or physically simulated versions of the systems being evaluated, and the goal of this methodology is the benefit assessment of a (decision aid) system *before* any version of it is actually built.

Further analysis of the model-derived estimation approach showed that the latter approach (e.g., application of the Human Operator Simulator) would require the use of extensive computational resources. Moreover, it would require a high degree of precision in the definition of the tasks and systems being assessed. Such a level of detail appeared inappropriate for the early design phase assessment intended here so this approach was eliminated from consideration. Most importantly, it would require the modeling and simulation of cognitive processes involved in decision making, and present operator models are incapable of doing so (see Zaklad, 1981a, 1981b).

On the other hand, Sheridan (1980) has suggested that subjective rating methods are surprisingly reliable and are especially simple and inexpensive to apply. Thus in the workload reduction portion of the benefit assessment methodology, subjective rating methods are utilized to measure the operator workload associated with each sequence of formal statements.

The workload measurement is accomplished by rating each formal statement in a sequence on subjective scales representing a number of appropriate workload dimensions and then summing the ratings over all the task statements in the sequence to yield operator workload ratings for the entire scenario evolution. This approach requires the subjective ratings be made on interval-valued scales so the summing operation can be legitimately done. The most reliable (and serendipitously the simplest) subjective rating device possessing this interval-value property is the Likert scale. Likert scales are discrete scales containing an odd number of scale values evenly spaced across a continuum representing the quantity being assessed. The middle value on the scale is explicitly assigned to the midpoint on the continuum, the highest and lowest values are explicitly assigned to each endpoint on the continuum, and any other values are explicitly assigned to evenly spaced points between the midpoint and endpoints. In the workload assessment procedure, each workload measure for which a Likert scale was required* was given a five-point scale as follows:

0 -- indicating *no* workload of this type associated with the task,

1 -- indicating *low* workload of this type associated with the task,

2 -- indicating *medium* workload of this type associated with the task,

*Some measures can use more objective scales, as discussed below.

3 -- indicating *high* workload of this type associated with the task, and

4 -- indicating an *overload* of work of this type associated with the task.

A total of 13 individual workload measures were defined and divided into the following four general categories:

- Cognitive Workload Measures,
- Psychomotor Workload Measures,
- Motor Workload Measures, and
- Interactional Workload Measures.

The *cognitive* measures are used to assess the levels of various kinds of mental work required by a given task. The *psychomotor* measures are used to assess the levels of various kinds of coordinated mental/motor-manipulation work required by a given task. The *motor* workload measures are used to assess the levels of various kinds of manual manipulation work required by a given task. *Interactional* measures are used to assess the levels of various kinds of communication required by a task and the various effects of interruptions which may occur within the given task.

The entire list of workload measures is given in Table 2-1, along with the category to which each belongs and the scale on which it is measured. As can be seen in Table 2-1, measures such as "Button-Pushing Frequency" and "Keyset-Entry Frequency" posses a natural interval-valued scale and therefore do not require use of a Likert scale. The "Magnitude of Interruptions" measure is a special case and requires further explanation. It is measured on an open-ended integer scale with a procedure based on Katz (1979). When each operator function is defined, it is assigned an importance or priority value. A priority of three indicates the procedure must be performed *immediately* and cannot be interrupted by anything except a priority-one procedure. A priority

TABLE 2.1. WORKLOAD MEASURES FOR DECISION-AID BENEFIT ASSESSMENT

Workload Category	Workload Measure & Abbreviation	Scale Values	Additional Subjective Assessment Criteria
COGNITIVE	Planning Difficulty (PLD)	0 None 1 Low 2 Medium 3 High 4 Overloaded	Planning time horizon available, Flexibility in plan being constructed, Accuracy in plan being constructed, Time frame being planned for, No. of planning factors involved.
	Prediction Difficulty (PRD)	0 None 1 Low 2 Medium 3 High 4 Overloaded	Time available for prediction, Uncertainty in process being predicted, Required accuracy in prediction, Time period to which prediction applies, Complexity of process being predicted.
	Calculation Complexity (CLC)	0 No calculation 1 can be done 'in the head' 2 Can be done by a calculator 3 Can be done only on digital computer	NONE
	Information Processing Complexity (IPC)	0 None 1 Low 2 Medium 3 High 4 Overloaded	Kind of function(s) involved, Number of arguments to functions involved.
	Information Absorbtion Complexity (IAC)	0 None 1 Low 2 Medium 3 High 4 Overloaded	Form of information presentation, Signal-to-noise ratio, Figure-to-ground clarity, Amount of information presented.

TABLE 2.1. WORKLOAD MEASURES FOR DECISION-AID BENEFIT ASSESSMENT (continued)

Workload Category	Workload Measure & Abbreviation	Scale Values	Additional Subjective Assessment Criteria
PSYCHO-MOTOR	Trackball Movement (TBM)	0 None 1 Low 2 Medium 3 High 4 Overloaded	Amount of clutter on screen, Accuracy at required end-point, Tracking or static movement.
	Writing (WTG)	0 None 1 Form Completion 2 Sketching 3 Summarization	Information being recorded, Recording format.
MOTOR	Button-pushing Frequency (BPF)	No. of pushes involved	NONE
	Keyset entry Frequency (KEF)	No. of entries involved	NONE
INTER-ACTIONAL	Interruption Frequency (IFQ)	No.of procedures interrupted in fixed time interval	NONE
	Interruption Magnitude (IMG)	Level of importance of interrupted procedures	Importance (priority) scale of procedures.
	Communications Frequency (CFQ)	Number of speech encodes/decodes per unit of time	Each complete utterance is considered as 1 encode for speaker, 1 decode for listener.
	Communications Complexity (CMC)	0 None 1 Low 2 Medium 4 Very High	Whether communication is one- or two-sided, Syntactic freedom of messages, Background noise levels.

of two indicates the procedure must be performed *as soon as possible* and can be interrupted only by a priority-three procedure. A priority of one indicates the procedure can be performed *whenever there is time* and can be interrupted by either a priority-three or -two procedure. When a procedure is interrupted by a higher-priority procedure, it is placed on a stack corresponding to its priority. When the interrupting procedure is finished, the interrupted procedure is returned to unless there is another of higher priority queued on a different stack. Similarly, if a procedure becomes active but cannot interrupt the current one because it lacks sufficient priority, it is queued until it can be activated. The magnitude of interruptions for a given task is measured by summing the number of stacked (i.e., interrupted) procedures on each stack, multiplying the number by the priority of the stack, and summing across stacks.

In developing actual measurements of operator procedures, a Delphi panel of raters is first established. This panel should represent both operational experience with the kinds of tasks being considered, and human engineering expertise with the analysis and measurement of workload. Each rater then assigns a value from the subjective scale of each workload measure to every HOPROC statement constructed for the specific aiding condition and scenario. For each workload measure assessed on a Likert scale, a number of criteria are defined to aid in the scaling process. These criteria are also given in Table 2-1. When a given task is being rated, the raters are instructed to weigh in their minds all the criteria listed in Table 2-1 for that measure, and only those, before selecting a specific scale value. This helps ensure a consistency in rating criteria across raters, usually a substantial problem in subjective rating procedures. The degree of specificity in the HOPROC representations is sufficient to allow a meaningful assessment of the workload measures involved, given the level of precision appropriate for an early-design-stage evaluation of this sort. And because the HOPROC representations are logical rather than physical in nature, the resulting ratings are not strongly tied to any detailed physical interpretation of the candidate aid design, again appropriate for this stage of aid development.

2.5.1 Combination of Rating Sums into Composite Workload Scores

After the 13 workload measures are applied to each statement in a pidgin-HOPROC sequence representing TACCO actions in a given scenario evolution, the scores are summed across all the statements in the sequence. This produces a vector of rating scores, each value of which represents the summed total of the workload scores assigned to the sequence on the specific workload measure. When there are multiple raters, there is one such vector for each individual and/or group doing the rating. However, in order to compare aided and unaided workload for a given scenario, it is necessary to arrive at single numbers representing unaided operator workload (UWL_i) and aided operator workload (AWL_i). Thus, the rating vectors must be combined both across raters and across workload measures. This is accomplished by averaging the rating vectors across all raters to arrive at a composite or average rating vector and then applying a combination rule (i.e., a function of the 13 workload measures shown in Table 2-1) which yields a single value for this average rating vector.

The generation of an appropriate combination rule presented a nontrivial problem because of the severe constraints involved. In combining the 13 workload measures, the rule had to take into account the fact that these measures are not of equal importance and probably highly correlated. Moreover, the rule also had to take into account the subjective perceptions that experienced operators (i.e., TACCOs) have of their own workload, so that the resulting aggregated scores (UWL_i and AWL_i) reflect real-world workload. A psychometric procedure was devised and applied to create a combination rule which met these constraints to as great a degree as possible. This procedure utilizes the statistical method of stepwise multiple linear regression (SMLR) and the perceived workload rankings for 14 representative TACCO decision functions collected from 54 highly-experienced TACCOs during the previous phase of this research.

SMLR is a linear statistical technique used to develop a function which calculates the value of a dependent or predicted variable from the values of a number of independent or predictor variables. It differs from standard multiple linear regression in that it utilizes an iterative procedure which on any given iteration considers the relationship between only one of the predictor variables and the predicted variable or its remaining unpredicted variance (called its *residual*). On the first iteration SMLR selects the predictor variable which explains the largest amount of the variance in the predicted variable, and computes a regression coefficient and constant which best calculate the value of the dependent variable. It then calculates the residual by subtracting the predicted value of the dependent variable from the actual value, and begins a new iteration by determining which of the remaining predictor variables best explains this residual variance. This iterative procedure continues until all predictor variables have been included. This procedure minimizes the effects of correlations among predictor variables by eliminating the variance in the predicted variable that is explained by one variable before the effect of a second (correlated) predictor variable is considered.

In the problem of interest here, the dependent variable can be defined as the average workload rank assigned to each of the 14 TACCO decision functions, as calculated from data in Zachary (1980b). The predictor variables would then be the 13 workload measures indicated in Table 2-1 as applied to these same 14 TACCO functions. The result of an SMLR analysis of these data is a linear additive formula which calculates the aggregate workload rating of a given task from values obtained by applying the 13 workload measures to that task. While the additive linear nature of this technique might appear to require some strong assumptions, a consideration of the problem shows that this is not the case. Although it cannot be demonstrated that each of the 13 measures has a strictly linear effect on overall workload, it is clear that a strictly monotonic relationship does exist. That is, workload clearly increases as any of the individual types of work measured by the 13 workload scales increases. Moreover, each of the 13 scales used possesses interval scale properties, so it is legitimate to model their effects as additive. Thus, even though a strictly linear model may not be totally accurate from a theoretical perspective, its use as an approximational device is certainly justified.

The use of SMLR in this manner has two major benefits. First, it results in a combination rule which produces workload scores that are consistent with fleet perceptions of workload. Second, it yields a rule with this property regardless of the individuals doing the rating. This means that overall workload scores which reflect the perceptions of experienced operators can be generated without requiring the raters used in the benefit assessment procedure to have extensive operational experience. Also, it results in a combination rule which compensates in large measure for interdependencies among the workload measures shown in Table 2-1. One drawback, however, is that it results in workload measures which have only interval scale properties. This is because the average rankings used as the dependent variable in the SMLR reflect only relative, not absolute, workload values.

To construct the needed combination rule, each of the 14 decision functions ranked by the TACCOs in Zachary (1980a) was formalized into a sequence of pidgin-HOPROC statements and rated on each of the workload measures shown in Table 2-1. The ratings were then summed down each sequence and averaged across raters to produce an average rating vector for each of the 14 tasks. The SPSS program (see Nie, *et al. 1975*) which performs SMLR was then used to construct a composition rule for the 13 workload measures which incorporated the perceptions of the experienced TACCOs as represented by their perceived workload rankings of the 14 decision functions. The function which resulted is:

$$\begin{aligned} \text{WL} = {} & +2.7\ \text{PLD}-1.08\ \text{PRD}-.067\ \text{CLC}-.64\ \text{IPC}+.282\ \text{INC}+ \\ & .266\ \text{TBM}+.8311\ \text{WTG}-.215\ \text{BPF}+.297\ \text{KEF}+.003\ \text{IFQ}+ \\ & 1.97\ \text{IMG}+.417\ \text{CFQ}+.002\ \text{CMC}+5.97 \end{aligned} \tag{2.3}$$

The variable-names in this function are abbreviations of the workload measures and are also shown in Table 2-1. This function was subsequently used in the workload assessment of the Sonobuoy Pattern Planning and Attack Planning decision aid, as described in Sections 4 and 5.

3. METHODOLOGY FOR COST ASSESSMENT OF CANDIDATE DECISION AIDS

3.1 OVERVIEW OF COST ASSESSMENT METHODOLOGY

The introduction of any new system into a tactical military environment may result in numerous benefits of the kinds discussed in Section 2. But since no system is without cost, it is also important to consider the costs of developing and implementing a candidate decision-aiding system along with the benefits the system may bring. This section describes a general methodology that can be used to assess the costs of candidate decision aids for Naval Air ASW. The general strategy used in Section 2 for decision-aid benefit assessment was to break each type of benefit into its constituent aspects, measure each of these individually, and then sum the measurements to get an aggregate benefit figure. An analogous strategy is used in this section for cost assessment of decision aids. The aid is initially broken down into its constituent component and subcomponent units, after which the various kinds of costs that will be incurred during its life cycle are identified. Next, each kind of cost is separately estimated for each component and subcomponent of the decision-aiding system. These costs are then summed to yield a total system life-cycle cost. Generically, life-cycle costs of a system are composed of research and development, investment, and operating and support cost items.

Although no cost assessment was performed in the research reported here, the methodology described below was developed to the point that it could be directly applied to the two decision aids considered here for benefit assessment, or to any other decision aids for Naval Air ASW. In specifying the methodology to this level of detail, it was necessary to make several assumptions and construct several definitions. Two of these in particular require more detailed discussion before the full cost assessment methodology is presented.

3.1.1 Assumptions and Definition for Decision-Aid Cost Assessment

The most important assumptions made in constructing the cost assessment methodology concern the ways in which decision aids would be implemented in the Air ASW environment. In specific, it was necessary to assume what (if any) new hardware would be required by the introduction of decision aids into ASW aircraft. The conclusions of a previous study (Kelley *et al.* 1981) on the feasibility of implementing decision aids in air ASW aircraft provided guidance in making these assumptions. It was concluded in that study (and it is assumed here) that the introduction of decision-aiding systems into Naval air ASW aircraft will require the introduction of up to three new pieces of equipment: a digital processor dedicated to decision-aiding calculations, a tape-overlay drive to increase on-board core storage capacity and a digital data bus to allow the new processor to communicate with other on-board computers. The introduction of decision-aiding systems to the LAMPS MK III helicopter requires no additional hardware since the decision-aid calculations can be performed on-board the (data-linked) ship. On the S-3A, such systems may require a dedicated digital processor and data bus, while on the P-3C, *either* a processor and bus *or* a tape-overlay drive may be required.

In developing the cost assessment methodology, it was necessary to define precisely what would and would not be considered as a cost of a decision-aid system. The costs of a decision aid could be narrowly defined to include only the obvious costs, such as the cost of designing the aid, the cost of building the necessary models, and the cost of programming the aiding software. Alternately, the costs could be broadly defined to include all secondary and tertiary costs, such as the cost of modifying support facilities or the cost of providing and training maintenance personnel for the new hardware required by the aid. While a narrow definition would make the cost assessment task simpler and easier, it was felt that it would also make any resulting cost estimate unrealistic. The secondary and tertiary costs included under the broad definition would be real costs, even though their sources might be less visible than sources of the costs included under the narrow definition. To exclude such costs would present an incomplete and inaccurate picture of the overall cost of the decision aid. At the same time, the use of the broad definition of decision-aid costs would allow many secondary *savings* arising from decision-aid introduction to be included in the cost assessment procedure while the narrower definition would not. For example, the introduction of a decision aid would permit the elimination and removal of several dials, switches, displays, and software modules currently in use on the ASW aircraft. As a result, procedures to train operators in the use of these items could be eliminated and support personnel and equipment used to maintain these items could be freed for other tasks. This would lead to considerable savings which could be viewed under a broad definition as direct consequences of the decision aid. These savings could now be included in the decision aid's cost by subtracting them from the overall cost of the decision aid to yield a net cost. It was therefore decided to define the costs of a decision aid as broadly as possible and to include *all* costs and savings resulting from the decision aid in the final cost estimate.

3.1.2 General Cost Assessment Procedure for Air ASW Decision Aids

The general methodology for cost assessment of air ASW decision aids contains two parallel paths, each of which contains three broad steps. One path concerns the calculation of the overall or *gross costs* of the decision-aiding system being assessed, and the other concerns the overall or *gross savings* that might result from the decision-aiding system. After the gross costs and gross savings have been estimated, the two paths merge as the savings are subtracted from the costs to yield a *net economic cost* of the decision aid.

Both of these paths use three analogous steps to arrive at their final cost or savings estimate. In the first step, the system involved is decomposed into constituent units, so that each unit can be separately assessed for specific costs and/or savings which it may incur. This decomposition results in what is known as a System Structure Breakdown (SSB) diagram -- a line-and-block diagram showing the relationships among all the constituent components and subcomponents. In the cost path, the system for which the SSB is constructed is the decision aid itself, while in the savings path, the systems for which the SSB is constructed are those which may be eliminated as a result of the decision aid's introduction.

The second and third steps differ slightly betwen the cost and savings paths. In the second step on the cost path, individual types of generic costs which may arise during the research and development, the acquisition and implementation, and operation and support of a system are defined. This yields a generalized cost structure. Each system component and subcomponent identified in the SSB is then matched with each of these cost types to determine which types of costs will be incurred by which system components/ subcomponents. In the third step on the cost path, each type of cost determined to apply to each system component/subcomponent is subjected to a quantitative estimation procedure, by which the actual dollar value of that cost for that component is estimated. When all costs for all components have been estimated, they are summed to produce an overall gross cost estimate.

On the savings path, the second step also begins with an identification of generic cost elements. These elements are then compared against the components/subcomponents in the SSB of the systems to be eliminated, to define costs which are presently incurred but which will no longer be incurred once the decision aid is implemented. In the third step on the savings path, the costs to be eliminated are then quantitatively estimated and summed to produce an overall savings from the decision aid.

A procedure which operationalizes this methodology is pictured in Figure 3-1. The procedure begins with a design for a specific decision aid, just as the benefit assessment procedure shown in Figure 2-1 did. From this design, a decision-aid SSB is initially constructed. Next, using appropriate documentation on the characteristics of the platforms and their ship-based or land-based support facilities, a set of alternative implementations for the decision aid is developed. In some cases, there may be only one implementation considered, but in other cases there may be several, and it is desirable for the

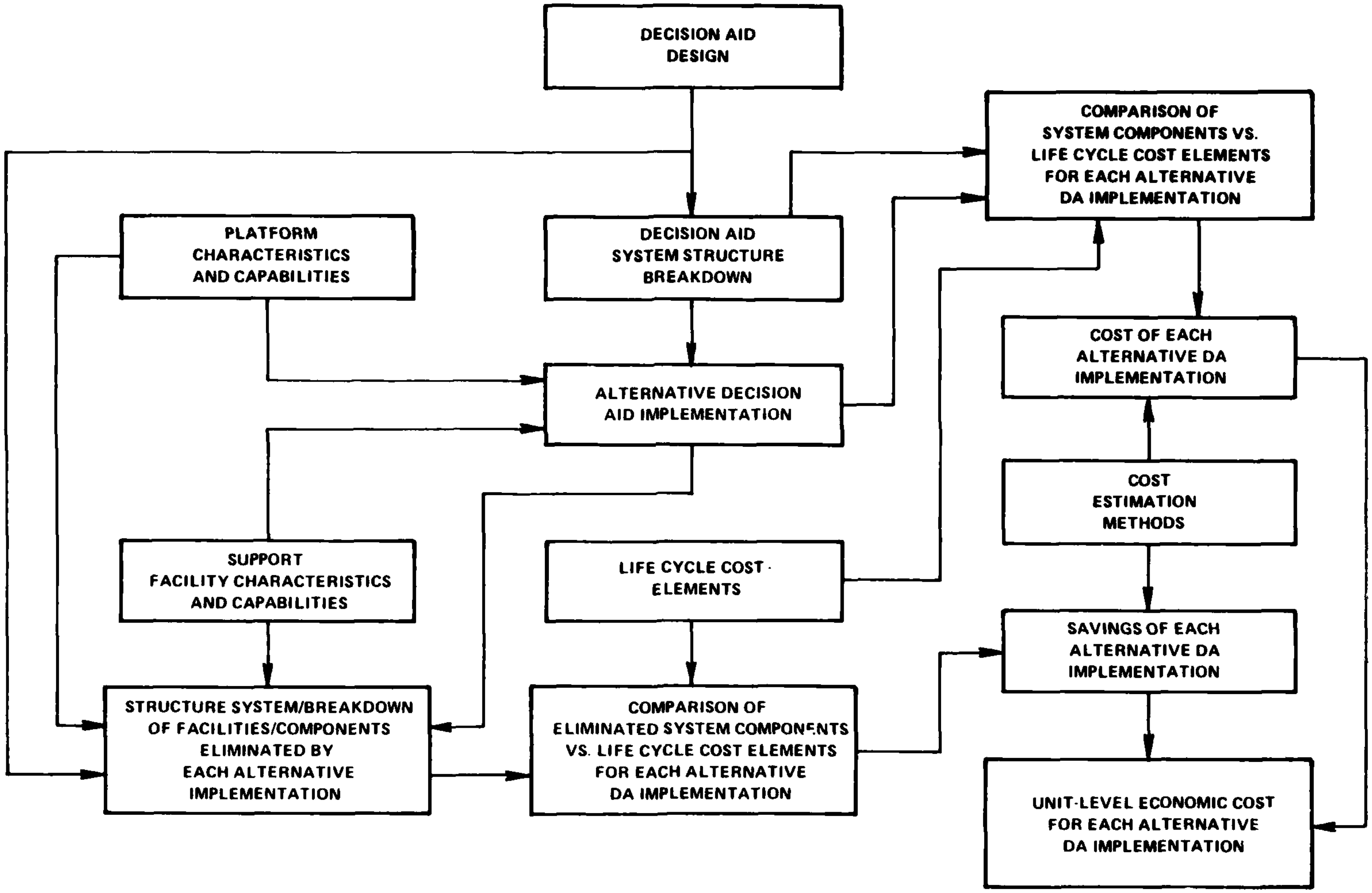

Figure 3-1. Cost Assessment Methodology for Candidate Decision Aids

cost-assessment method to allow cost comparisons among the implementation alternatives to be made.

The set of systems and/or system components presently in the ASW aircraft (or its support facilities) that can be eliminated upon implementation of the decision aid is then defined. The decision-aid design and data on the characteristics of the platform(s) and support facilities are used in this step also. An SSB of these systems/components is constructed next. These two SSBs -- one for the eliminated components and one for the decision aid itself -- mark the beginning of the savings and cost paths, respectively.

After the SSBs have been constructed, the various types of costs or *cost elements* which arise during each phase of a decision aid's life cycle are identified and listed. The resulting lists of life-cycle cost elements are then assessed against each system component/subcomponent identified in each SSB to determine which cost elements apply to each system component. A separate comparison is made for each implementation alternative.

When all the cost element versus system component/subcomponent comparisons are completed, the process of estimating those costs identified in the comparisons is initiated. The cost estimation process is then undertaken to estimate the unit-level dollar cost of each cost element determined to apply to each system component/subcomponent for each alternative implementation. The individual cost estimates are then summed for each alternative to produce unit-level, implementation-specific, gross-cost and gross-savings estimates. Finally, the gross-savings estimates are subtracted from the gross-cost estimates to produce a unit-level economic cost for each possible implementation of the decision aid.

The following subsections describe the major steps in this procedure in greater detail. Section 3.2 discusses the construction of the SSB, Section 3.3 discusses the identification of cost elements and the ways of assessing them against the system components/subcomponents, and Section 3.4 discusses the techniques commonly used for cost estimation.

3.2 AIR ASW DECISION-AID SYSTEM STRUCTURE BREAKDOWN

Before the costs of any system can be assessed, the system must first be divided into its lower-level component and subcomponent units, so that individual costs can be separately assessed for each of them. To demonstrate SSB development, an SSB was constructed for a generic Air ASW decision aid, in accordance with MIL-STD 881A. The SSB diagram is shown here as Figure 3-2. Any specific decision aid for airborne ASW will retain most of the features of the general system structure shown in Figure 3-2, although certain differences at the subcomponent level may arise. When a cost assessment of a specific decision-aiding system is undertaken, the breakdown given in Figure 3-2 should be adjusted to reflect the detailed characteristics of the decision aid involved.

As shown in Figure 3-2, there are five major components of a generic air ASW decision-aid system. Each major component can be thought of as a collection of individual subcomponents. The five components for Air ASW decision aids contain its:

- Major equipment subcomponents,
- Auxiliary equipment subcomponents,
- System software subcomponents,
- Common support equipment subcomponents, and
- System-level and integrative subcomponents.

Major equipment subcomponents are those items of hardware and equipment that are used exclusively for the dec, ion-aiding system. *Auxiliary equipment* subcomponents are those items of hardware utilized by the operational decision- aiding system that are also utilized by other systems on-board the

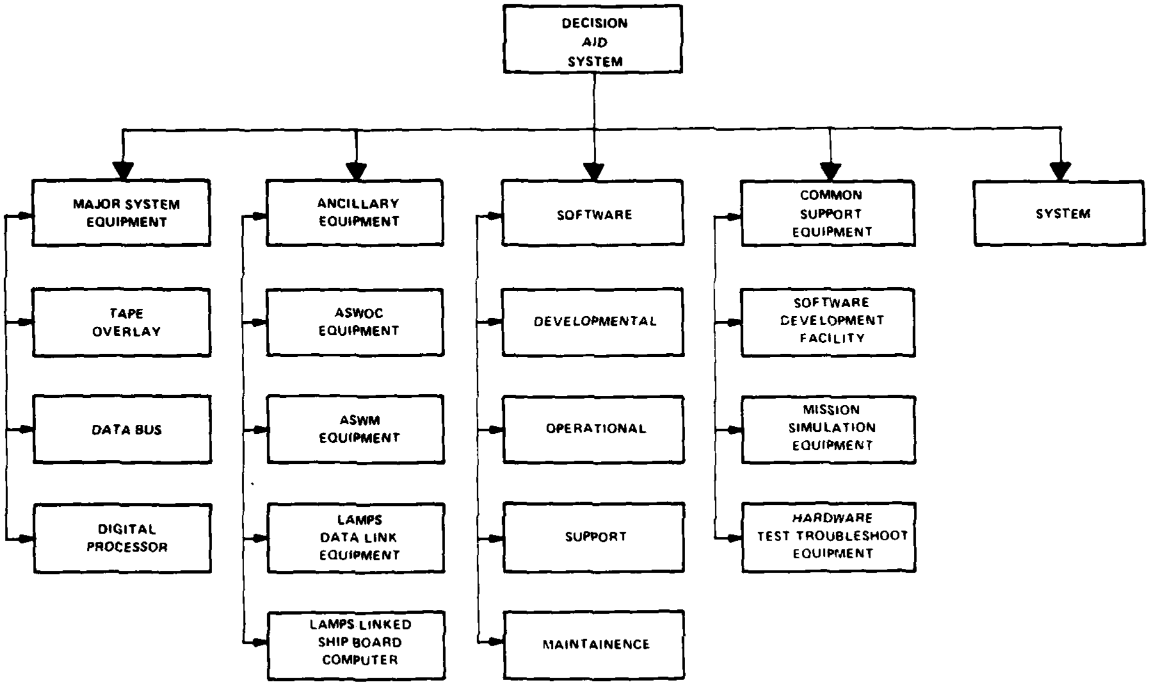

Figure 3-2. System Structure Breakdown for Generic Air ASW Decision Aid

aircraft or on the ground. *Common support equipment* subcomponents are those items of equipment which are used to support the development, implementation, and/or operation and maintenance of the decision-aiding system and other non-decision-aid systems as well. (An additional major component normally present in SSB diagrams -- special or peculiar support equipment -- includes those items of equipment used only to support the decision-aiding system. However, since no such equipment was identified, this component was not used in Figure 3-2.) *System software* subcomponents are all the computer programs used by the decision aid in any phase of its life cycle. *System integrative* subcomponents are those subcomponents and aspects of the decision aid which integrate its separate components and subcomponents into a single, whole unit. This component also includes the entire system itself as a functioning entity independent of its lower-level constituent parts or their characteristics.

Three subcomponents of the major equipment component are shown in Figure 3-2. These are a tape-overlay drive, a data bus, and a digital processor. The need for these items as essential to the practical implementation of a decision-aiding system on-board Air ASW platforms is discussed in Kelley *et al.* (1981). As discussed above, one or more of these items may not be needed, depending on the specific platform being considered -- P-3C, S-3A, or LAMPS MK III.

Four subcomponents of the auxiliary system equipment component are shown in Figure 3-2. These are the ASWOC (Anti-Submarine Warfare Operational Control) facility, the ASWM (Anti-Submarine Warfare Operational Model) facility, the LAMPS data-link equipment, and the LAMPS-linked shipboard computer. The first two subcomponents (ASWOC and ASWM) are considered as components of the decision-aid system because the decision-aid software must interface with them during the preflight briefing and post-flight analysis portions of the mission. Data from the decision aid must be made available to the ASWOC/ASWM computers after landing so that proper post-mission analysis can take place; data from the ASWOC/ASWM computers must be made available to the decision-aid software before the decision aid must be made available to the ASWOC/ASWM computers after landing so that proper post-mission analysis can take place. And data from the ASWOC/ASWM computers must be made available to the decision-aid software before takeoff so that the decision aid's computations can be based on the best available predictions and intelligence information. Thus, the ASWOC and ASWM are integral although background components of the overall decision-aiding system.

The second two subcomponents listed under auxiliary system equipment in Figure 3-2 apply only to the LAMPS MK III platform. On this platform, the decision aid will reside on the ship-based computer to which the LAMPS helicopter is linked. Thus, both the data link equipment and shipboard computer must be considered as subcomponents of the decision-aiding system. They are listed as auxiliary equipment because they support many other functions on-board the LAMPS vehicle and the ship besides the decision aid.

Four subcomponents of the system-software component are listed in Figure 3-2. These are the developmental, operational, support, and maintenance software programs in the decision-aid system. Developmental software refers to any and all programs created during the research and development of the decision aid. Operational software includes any and all programs used by the decision aid itself in its operational environment. Support software includes any and all programs used to support the decision aid's operation, e.g., post-processing programs at the ASWOC/ASWM to analyze the decisions made by the decision aid during the mission just completed. Maintenance software includes any and all programs used to test, troubleshoot, and maintain the other three types of software.

Three subcomponents of the common support equipment component are listed in Figure 3-2. These are the Software Development Facility (at NADC), the necessary mission simulation equipment, and the hardware test/troubleshoot equipment. The Software Development facility is the testbed at NADC on which operational software for airborne platforms is developed. During development, takeoff so that the decision aid's computations can be based on the best available predictions and intelligence information. Thus, the ASWOC and ASWM are integral although background components of the overall decision-aiding system.

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Three subcomponents of the common support equipment component are listed in Figure 3-2. These are the Software Development Facility (at NADC), the necessary mission simulation equipment, and the hardware test/troubleshoot equipment. The Software Development facility is the testbed at NADC on which operational software for airborne platforms is developed. During development, test, and evaluation phases of the decision aid, it will be necessary to interface the developmental and/or prototype decision-aid system with equipment which simulates inputs the system would receive in a true operational environment. This is the equipment indicated as "mission simulation equipment" in Figure 3-2.

During all phases of the decision-aiding system's life cycle, various kinds of equipment will be needed to troubleshoot and test its various hardware components; this is the hardware listed in Figure 3-2 as "hardware test/trouble-shoot equipment."

The five system components and 14 system subcomponents shown in Figure 3-2 represent the units to which detailed cost identification and estimation procedures are applied in the final two phases of the cost-assessment procedure. If the specific decision aids being subjected to cost assessment have slightly different system structures than that shown in Figure 3-2, then a modified SSB reflecting their specific structures should be used in the subsequent cost identificaiton and cost estimation steps in the overall cost-assessment procedures.

3.3 LIFE CYCLE COST IDENTIFICATION

Life cycle cost or LCC analysis is a method for assessing all costs incurred during the projected life of the system being considered. It covers all costs necessary to develop, acquire, operate, and maintain the system over its useful life. The LCC analysis breaks down the costs associated with a system into those which arise in its three major life-cycle phases:

- Research and development,
- Acquisition and implementation, (or investment), and
- Operation and support.

Costs arising in these three phases are then combined to produce an overall LCC estimate as shown in Figure 3-3.

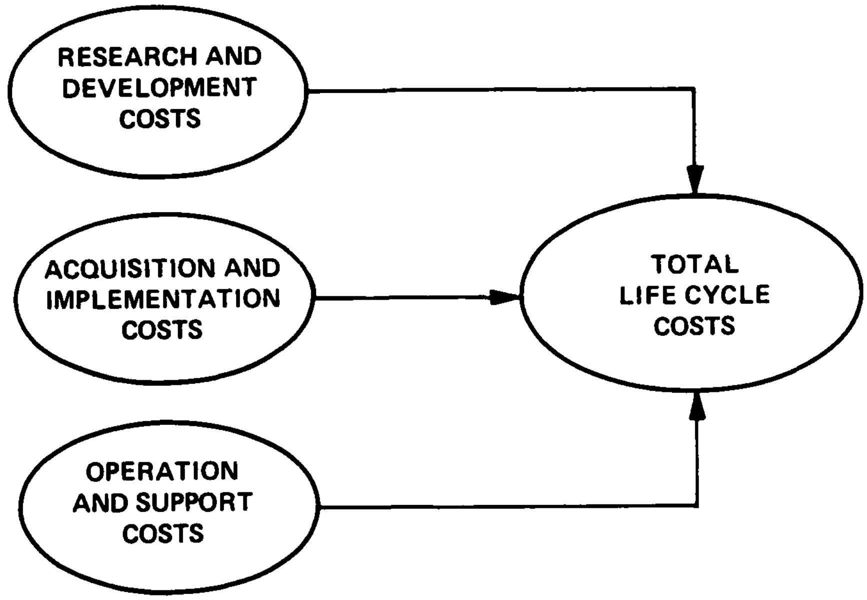

Figure 3-3. Three Phases of Life Cycle Cost

Figure 3-3. Three Phases of Life Cycle Cost

3.3.1 Life Cycle Cost Structure

Substantial efforts in all branches of the Department of Defense to develop consistent methodologies for cost analysis have led to the creation of a standardized decomposition of the costs in each life-cycle phase into well-defined, individual costs or *cost elements*. The specific cost elements which are relevant to the research and development of any system are indicated in Table 3-1. The specific cost elements which are relevant to the acquisition and implementation of any system are indicated in Table 3-2. The specific elements which are relevant to the operation and support of any system are indicated in Table 3-3. Detailed definitions of the individual cost elements within each category can be found in References 5, 6, 7, and 13.

Table 3-1. Research and Development Cost Elements

COST ELEMENT
Development Engineering
Producibility Engineering and Planning
Tooling (for R&D effort only)
Prototype Manufacturing
Data (Documentation of R&D efforts)
System Test and Evaluation
System/Project Management
Training Services and Equipment (Training of R&D Users, such as experiment subjects for evaluation procudure)
Facilities (for R&D efforts)
Other

Table 3-2. Implementation Cost Elements

COST ELEMENT
Non-Recurring Investment Cost Elements
Initial Production Facilities
Industrial Facilities/Production Base Support
Other Non-Recurring Investment Costs
Production Cost Elements
Manufacturing
Recurring Engineering
Sustaining Tooling
Quality Control
Other
Engineering Changes
System Test and Evaluation
Data (Documentation of Implementation and Operational Training Material)
System/Project Management
Operational Site Activation
Training Services and Equipment (for System Implementation)
Initial Spares and Repair Parts
Transporation
Other

Table 3-3. Operating and Support Cost Elements

COST ELEMENT
Military Personnel Cost Elements
Crew Pay and Allowances
Maintenance Pay and Allowances
Indirect Pay and Allowances
Permanent Change of Station
Consumption
Replenishment Spares
Petroleum, Oil and Lubricants
Unit Training, Ammunition and Missiles
Depot Maintenance
Labor
Materiel
Transportation
Modifications, Materiel
Other Direct Support Operations
Maintenance, Civilian Labor
Other Direct
Indirect Support Operations
Personnel Replacement
Transients, Patients and Prisoners
Quarters, Maintenance and Utilities
Medical Support
Other Indirect

In assessing the costs (and savings) from a decision-aiding system, the various LCC elements indicated in Tables 3-1 through 3-3 must be considered against each specific decision-aiding system component and subcomponent identified in Figure 3-2. This consideration is undertaken to determine which specific cost elements would be incurred by each component and subcomponent of the system being assessed. The results of this procedure are normally summarized in matrix form. For each life-cycle phase, a matrix is constructed in which the rows represent the relevant cost elements and the columns represent the system components and subcomponents from the SSB. When a given system component or subcomponent is determined to involve some cost of the kind represented by a given cost element, a check is placed in the cell of the matrix where the row representing the cost element and the column representing the system component or subcomponent intersect. After all cost elements have been considered against all system components/subcomponents, those cells in the matrix which have checks represent the component-specific costs which may arise in that phase of the system's life cycle. Each of these individual costs are then subjected to cost estimation procedures which are described in Subsection 3.4 below.

3.3.2 Life Cycle Costs for Air ASW Decision Aids

The SSB of the generic air ASW decision aid shown in Figure 3-2 was compared against the LCC elements (shown in Tables 3-1 through 3-3) in the manner indicated above to demonstrate the cost identification process. The results of this comparison are summarized in Tables 3-4 through 3-6.

Table 3-4 shows the costs that arise in the research and development of the decision aid. In this phase of the life cycle, most costs are associated with the component labeled "system" in Figure 3-2; this reflects the fact that during early research and development, specific system components are not yet clearly defined. During this phase, extensive developmental engineering is required for all aspects of the system's software, including software for testing, support, and maintenance of the decision aid, as indicated by the checks in the row of the matrix labeled "developmental engineering." Full documentation of all research and development work is also required, especially for

Table 3-4. Research and Development Costs for Air ASW Decision Aids

COST ELEMENT / SYSTEM STRUCTURE COMPONENT	1 TAPE DRIVE	2 DATA BUS	3 DIGITAL PROCESSOR	4 AUXILIARY EQUIPMENT	5 COMMON SUPPORT EQUIPMENT	6 DEVELOPMENT SOFTWARE	7 OPERATIONAL SOFTWARE	8 SUPPORT SOFTWARE	9 MAINTAINENECE SOFTWARE	10 SYSTEM
DEVELOPMENT ENGINEERING						√	√	√	√	√
PRODUCIBILITY ENGR & PLANNING (PEP)										√
TOOLING										
PROTOTYPE MANUFACTURING	√	√	√							
DATA DOCUMENTATION						√	√	√	√	√
SYSTEM TEST AND EVALUATION					√					√
SYSTEM/PROJECT MANAGEMENT										√
TRAINING										√
FACILITIES										
OTHER										

the software subcomponents of the system. This is indicated by the numerous checks in the "data documentation" row in Table 3-4. In the final stages of research and development, full working prototypes of the hardware required for the decision aid (the tape overlay, data bus, digital processor, etc.) must be built, hence the checks in the hardware component columns of the "prototype manufacture" row. Finally, the necessary software simulators must be exercised during the testing and evaluation of the prototype system, and the cost for their use and maintenance during this period is anticipated by the check in the "common support equipment" cell of the "system test and evaluation" row.

Table 3-5 shows the costs that arise during the acquisition and implementation of the decision-aid system. There are two major "groups" of costs in this phase of the life cycle as shown by the two clusters of checks in Table 3-5. The entire decision-aid system must be documented, tested, and integrated with other systems on-board the ASW aircraft, its entire acquisition and implementation process must be managed, and existing flight personnel must be given additional training in its use. Thus, one major group of costs relate to the decision aid as a whole, and shows up as the series of checks in the column labeled "system." The other major group of costs is those associated with the hardware components of the system. These components must be purchased and initial spare parts and replacement units acquired. The hardware must then be transported to its place of installation and engineering changes (if any) necessitated by the installation process must be made. This second major group of costs thus shows up as a series of checks in the hardware columns of Table 3-5.

Table 3-6 indicates the costs that arise during the operation and maintenance of the decision-aiding system. In this phase, there are also two major groups of costs. One group consists of these costs associated with the maintenance of the software portions of the system, as indicated by the checks in the software/subcomponent columns of Table 3-6. The other major group consists of those costs associated with maintenance of the hardware components of the systems and is indicated by the numerous checks in the hardware/subcomponent columns of the matrix.

Table 3-5. Acquisition and Implementation Costs for Air ASW Decision Aids

COST ELEMENT \ SYSTEM STRUCTURE COMPONENT	TAPE OVERLAY	DATA BUS	DIGITAL PROCESSOR	AUXILIARY EQUIPMENT	COMMON SUPPORT EQUIPMENT	DEVELOPMENTAL SOFTWARE	OPERATIONAL SOFTWARE	SUPPORT SOFTWARE	MAINTAINENCE SOFTWARE	SYSTEM
NON-RECURRING INVESTMENT				√						√
PRODUCTION	√	√	√							
ENGINEERING CHANGES	√	√	√			√	√			
SYSTEM TEST AND EVALUATION										√
DATA DOCUMENTATION										√
SYSTEM/PROJECT MANAGEMENT										√
OPERATIONAL/SITE ACTIVATION										
TRAINING				√						√
INITIAL SPARES AND REPAIR PARTS	√	√	√							
TRANSPORTATION	√	√	√							
OTHER										

Table 3-6. Operation and Support Costs for Air ASW Decision Aids

COST ELEMENT \ SYSTEM STRUCTURE COMPONENT	TAPE OVERLAY	DATA BUS	DIGITAL PROCESSOR	AUXILIARY EQUIPMENT	COMMON SUPPORT EQUIPMENT	DEVELOPMENTAL SOFTWARE	OPERATIONAL SOFTWARE	SUPPORT SOFTWARE	MAINTAINENCE SOFTWARE	SYSTEM
MILITARY PERSONNEL										
CREW PAY & ALLOWANCES										
MAINTENANCE PAY & ALLOWANCES	✓	✓	✓	✓						
INDIRECT PAY & ALLOWANCES										
PERMANENT CHANGE OF STATION										
CONSUMPTION										
REPLENISHMENT SPARES	✓	✓	✓							
PETROLEUM OIL AND LUBRICANTS										
UNIT TRAINING, AMMO & MISSILES										
DEPOT MAINTENANCE										
LABOR	✓	✓	✓							
MATERIEL	✓	✓	✓							
TRANSPORTATION	✓	✓	✓							
MODIFICATIONS, MATERIEL	✓	✓	✓							
OTHER DIRECT SUPPORT OPERATIONS										
MAINTENANCE, CIVILIAN LABOR					✓		✓	✓	✓	
OTHER DIRECT							✓	✓	✓	
INDIRECT SUPPORT OPERATIONS										
PERSONNEL REPLACEMENT	✓	✓	✓	✓						
TRANSIENTS, PATIENTS & PRIS.										
QUARTERS, MAINTENANCE & UTILITIES										
MEDICAL SUPPORT										
OTHER INDIRECT										

3.4 COST ESTIMATION TECHNIQUES

After all the cells in the three LCC element versus system component comparison matrices have been filled in, all possible costs of developing, implementing, and operating the candidate decision-aid system are identified. Each checked cell in each matrix represents one specific kind of cost associated with one specific system component at one specific phase of its life cycle. Appropriate cost estimation techniques must then be applied to each such potential cost cell to determine its precise monetary level. Cost-estimating techniques can be placed into four major categories:

- Estimation by Analogy,
- Statistical Cost Estimation (Parametric Estimation),
- Industrial Engineering Estimation, and
- Judgmental (Expert Opinion) Estimation.

Each of these estimation techniques is discussed in greater detail in the following subsections.

3.4.1 Estimation by Analogy

The method of estimation by analogy is based on direct comparisons with historical information on like or similar systems, processes, assemblies, or components. The major drawback to the analogy method is that is is basically a heuristic process and as a consequence requires considerable experience and expertise to be effective. There are, however. occasions when the information available, or constraints imposed, will not support any other method of estimation. Analogy is used when there is little or no historical information available for the specific item and/or when the cost estimate is required so quickly that an extensive data search is precluded. There are two types of analogies which may be used. First, similar products can be compared, for example, using cost data on a commercial item to estimate costs of a military version. Second, when a new concept or system must be estimated, experience gained on a different but relatable product may be used. Although useful for making cost estimates on a "total" basis, this approach is not appropriate when a high degree of detail is required. When applied to advanced technology developmental systems such as decision aids, analogy estimates should be supported by expert opinion.

3.4.2 Statistical Cost Estimation (The Parametric Method)

The statistical cost estimation method can be used in deriving cost estimates in early system development. At this stage, system costs usually can be based only on preliminary physical and performance characteristics, and on their relationship to aggregated component costs. For constructing a statistical cost estimate, a functional relationship is established between total costs and various system characteristics or parameters.*

Many cost/parametric relations may be observed from historical data. In using statistics to develop cost/parameter relations from cost histories of prior programs, two possible problems must be kept in mind: (1) the uncertainty inherent in any application of statistics, and (2) the possibility that the resulting functional relationship is unreasonable or technically unsound. The first is unavoidable; however, the possibility of the second can be diminished through careful checks of the derived estimating relationships through inspection, data plots, or by more complicated techniques which involve investigating each parameter over a wide range of possible values, e.g., response surface methods.

3.4.3 Industrial Engineering Estimation

The industrial engineering approach consists of a consolidation of estimates from various detailed "work packages" into a total project estimate.

*For cost estimating purposes, a parameter is considered to be a definable and quantifiable characteristic of a system, component, or process.

Estimating by the engineering method is normally based on extensive detailed knowledge of the product design and, hence, is applicable primarily to systems at or near the production stage of development. Using the engineering method, each prime system hardware component is broken down into its lowest level subcomponents. Cost estimates are then made for each of these minimal components. Then these component cost estimations are combined -- along with estimates of the costs for integrating the components -- to arrive at a total system cost. An advantage to this method is that it separates out the parts of the system for which few data are available or which represent new those parts which can be analyzed more conventionally. This method has several drawbacks:

- The level of engineering detail required may not be readily known,
- The level of reliance on individual expertise and experience is high,
- Inputs are usually required from multiple individuals and organizations,
- Extensive time and labor are usually required to apply it, and
- Differences between estimated and actual costs on very minor or low-level system components can cause large total-cost estimation errors because of the cascading effects of compounding costs.

For these reasons, engineering estimation methods are often avoided, when a new product is involved and the estimator must work from limited sketches, blueprints, and prose descriptions of an item which has not been completely designed. In such cases it is very easy for the complexity of the work involved to be greatly overestimated or underestimated. Thus, the engineering approach is more difficult to apply (and often more unreliable) for complex systems or for processes during the early stages of development, such as decision aids.

3.4.4 Expert Opinion (Judgment) Estimation

Expert opinion may be defined as the comprehensive knowledge of a system by an individual or group that is required to reach a conclusion not directly supported by data. The necessity of using experienced judgment to fill in gaps in data has long been recognized, but judgment should only be employed by thoroughly experienced analysts and must always be recognized as basically an educated guess. The important consideration in using judgment must be reasonableness tempered with large doses of impartiality.

The use of expert opinion will continue to be necessary at times, but it must be recognized that it is subject to large inaccuracies. The estimator who used expert opinion in the preparation of cost estimates must be aware of its drawbacks. The best use of expert opinion is to check an estimate obtained by other means. However, when expert opinion must be used by itself in constructing a cost estimate (or some part of it), it is best to rely on formal methods such as Delphi panels to obtain the necessary judgment data.

4. BENEFIT ASSESSMENT OF THE SONOBUOY PATTERN PLANNING DECISION AID

A methodology for assessing the benefits that could be expected from the introduction of a candidate decision aid was described in Section 2 of this report. This section presents an application of that methodology to a specific decision aid for Air ASW sonobuoy pattern planning. This decision aid is intended for use throughout the Air ASW mission, but primarily in the On-Station Search, Localization, and Surveillance Tracking mission phases. It represents a generalization of four lower-level decision aids defined in Analytics (1981) -- the Search Planning decision aid, the Contact Investigation decision aid, the Contact Localization decision aid, and the Surveillance Tracking decision aid. In Analytics (1981), each of these aids uses an essentially identical algorithm to select a sonobuoy pattern for deployment in a specific mission phase; the aids differ only in the inventory of sonobuoy pattern geometries they store and consider in the pattern selection process. By combining their pattern geometry inventories into a single data base, the generalized decision aid is created. Because this generalized aid is applicable to three of the six decision situations identified as requiring decision aids in previous phases of this research (see Tables 1-1 and 1-2), its priority for further development is high.

Subsection 4.1 below reviews the overall structure and function of the Sonobuoy Pattern Planning decision aid. Subsection 4.2 describes the scenario tree constructed for the benefit assessment of this aid. Subsection 4-3 presents the results of applying the mission achievement gain portion of the benefit assessment methodology, and Subsection 4.5 presents the results of applying the operator workload reduction portion of the benefit assessment methodology.

4.1 THE SONOBUOY PATTERN PLANNING DECISION AID

During the ASW mission, the aircrew attempts to optimize utilization of the sonobuoys available to them. The initial use of sonobuoys is to gain contact with the threat target and after it is gained, it is refined though repeated deployment of additional sonobuoy patterns until a direct path contact is achieved. Although the crew receives information on suggested initial sonobuoy patterns at its briefing, these patterns are based upon predictions of environmental conditions which may or may not be valid for the search area at the time of the mission. Because of this reliance on predicted conditions, predetermined sonobuoy patterns may be significantly suboptimal when significant variations exist between the predicted and actual conditions. Once contact is gained with the submarine, the uncertainty in its location and track will vary, and this varying uncertainty will also affect sonobuoy pattern quality. The objective of the Sonobuoy Pattern Planning decision aid is to determine which pattern geometry and spacing is optimal given the current environmental conditions and target uncertainty.

The pattern selection task is first undertaken after the aircraft arrives on-station and obtains a bathythermal recording of the operating area oceanographic conditions. However, this pattern planning task will be repeated numerous times during the mission, as the prosecution of the target progresses. The Sonobuoy Pattern Planning decision aid assists the ASW TACCO in developing sonobuoy patterns throughout the mission by helping to incorporate into the pattern planning process data on the:

- in-situ environmental conditions,
- current uncertainty in the target's location, course, depth, and speed,
- current status of the aircraft's sensor inventory, and
- capabilities/characteristics of the target of interest.

The aid obtains its information on current aircraft sensor inventory from other on-board algorithms, and obtains its data on target capabilities/characteristics from a pre-stored data base provided to it prior to the mission via the Pre-Flight Data-Insertion Program (PDIP) tape. The other data, however, are calculated by the aid itself from inputs given it by the TACCO. The in-situ environmental conditions are calculated from the information gathered by the bathythermal and ambient noise recording sonobuoys deployed by the ASW aircraft immediately after it arrives on-station. The TACCO enters the information relayed by these sensors directly into the decision aid. The data on target uncertainty are calculated from one of two sources -- apriori Submarine Probability Areas (SPAs) or estimates of the target's location, course, and speed developed by the TACCO during the mission. SPAs are mathematical descriptions of the ocean area in which the submarine has a specified probability of being found. They are computed by ground-based or ship-based ASW support facilities from permament sensor data, intelligence data, and/or post-flight analysis of data from previous ASW flights and are supplied to the ASW aircraft prior to takeoff or while it is enroute to the target area. SPAs are used to represent the target uncertainty prior to initial contact. After initial contact has been gained, TACCO-supplied estimates of target location, course, depth, and speed are used to represent the target uncertainty.

The decision aid maintains a data base of basic sonobuoy pattern geometries and mission phases in which each is applicable. When the TACCO requests the aid to suggest sonobuoy pattterns, the aid first determines applicable pattern geometries either by locating all patterns that are applicable to the current mission phase, or (at the TACCO's discretion) by having the TACCO explicitly select the pattern geometries to be considered. Then, using a mathematical model of in-situ environmental conditions with the BT and AN sonobuoy information along with target uncertainty data, the aid determines an optimal pattern (geometry, spacing, and orientation) and several suboptimal ones. It then allows the TACCO to choose the one he deems best for the particular tactical situation at hand. In determining the optimal and near-optimal patterns, the aid uses the current sensor inventory to constrain the optimization process. If the ASW aircraft already has contact with the submarine at the point the aid is used, the aid also incorporates target characteristics and capabilities into the process by using this data to estimate the target's possible location, course, depth, and speed at the time the pattern is to be deployed. Once a specific pattern is selected by the TACCO, the aid then prepares the aircraft to deploy the pattern by setting up navigation information for the pilot and initiating the appropriate cueing sequences necessary to deploy each sonobuoy in the pattern.

The description of this aid is given above and contains all the information about it needed to assess its potential benefits in the current Naval Air ASW environment. Additional details on the algorithmic structure of this decision aid can be found in Kelley *et al.* (1981). This algorithmic structure was defined by the process developed in Zachary (1980a): the sonobuoy pattern planning decision was first analyzed and decomposed so as to uncover all the information needed to match decision-aiding techniques to it. The resulting information was then represented as a table (shown here as Table 4-1). The data in this table were matched with the decision-aid technique taxonomy developed in Zachary (1980a). This matching resulted in the selection of one or more techniques from each category in the taxonomy as applicable to a particular functional aspect of aiding the sonobuoy pattern planning decision. Details of the specific techniques selected and on their integration into a single decision-aiding algorithm for this aid can be found in the cited reference. A sample man-computer interface for the Sonobuoy Pattern Planning aid is presented in Section 6 below.

4.2 SCENARIO TREE FOR BENEFIT ASSESSMENT OF THE SONOBUOY PATTERN PLANNING AID

Numerous sonobuoy pattern selection decisions arise throughout the Air ASW mission and each is directly affected by all those which have preceeded it. To avoid having to deal with the problem of sorting out the decision aid's effects from all the interdependencies in a sequence of pattern selection

Table 4-1. Sonobuoy Pattern Planning: Summary of Decision-Aiding Requirements

Objective: Selection of optimal sonobuoy pattern, given in-situ environment conditions and target uncertainty.

Task Dynamics: Closed-loop iterative.

Underlying Process: Zero or more submarines moving in or through search area.

Value Criteria: Coverage area of pattern.
Probability of detection of submarine (P_d).
Probability of gaining direct path contact with submarine.

Variables and Parameters

Inputs
Oceanographic Conditions
- Propagation Loss (PL)
- Ambient Noise
- Sea State

Sensors Remaining
Target contact History

Outputs (Procesed Variables)
Pattern Coverage Area
Probability of Detection

Parameters
Sensors
- Type
- Capabilities

Available Pattern Geometries
Aircraft Capabilities
Target Capabilities
- Acoustical Emissions
- Movement Capabilities

Area of Search
- Operating Area
- Restricted Areas(s)

Decision Variables
Type and geometry of pattern to be deployed.
Spacing of buoys within pattern.

Relevant Analyses
1. Calculation in in-situ PL profiles.
2. Exclusion of patterns failing to meet mission restructions.
3. Determination of P_d for a given pattern.

Relevant Data
1. Pattern geometry and types and settings of sensors used.
2. Steering commands, cueing sequences, and fly-to-points for pattern deployment.
3. Target probability area and track data.

Requried Human Judgments
Final choice of pattern.

decisions, it was decided to assess the Sonobuoy Pattern Planning decision aid within the context of a single sonobuoy pattern selection decision -- the choice of the initial sonobuoy pattern through which contact with the submarine is first gained. This particular sonobuoy pattern selection decision is the ideal vehicle through which to examine this decision aid for two reasons. First, because this is the initial pattern selection decision in the mission, it is not dependent upon any previous sonobuoy pattern selection decision. Second, it is the most important sonobuoy pattern selection decision made during the mission. The initial search pattern normally includes the largest number of sonobuoys of any pattern deployed during the mission (up to 20), it covers the largest area of ocean of any pattern, and it takes the largest portion of on-station time to deploy of any sonobuoy pattern. Also, the entire fate of the mission depends on the quality of this decision, for if there is no initial detection, there can be no subsequent prosecution of the contact.

Two general mission contingencies which affect the quality of this search pattern selection decision were identified and used to form a scenario tree for the assessment of the Sonobuoy Pattern Planning aid. These are:

1. The Submarine Probability Area (SPA) which applies at the time the ASw aircraft arrives on-station, and

2. The accuracy of the pre-flight prediction of in-situ acoustic propagation conditons.

The importance of these factors stems from the way in which search patterns are currently selected. In present (unaided) procedures, the ASW aircrew is provided with an initial search pattern geometry, orientation, and spacing by the ground-based or ship-based support facility at its pre-flight briefing. This pattern is selected by support-facility computers through a full-scale pattern optimization procedure which is based on predicted acoustic propagation procedures and the SPA provided to the ASW aircrew at their pre-flight briefing. However, this SPA may subsequently be updated while the aircrew is enroute to the search area and the actual acoustic propagation conditions in the search area may be substantially different than those that were predicted. Thus, what was thought to be an optimal pattern prior to takeoff may turn out to be substantially suboptimal when ASW aircraft arrives on-station.

A scenario tree incorporating these two contingencies (SPA updates and differences between predicted and actual acoustic propagation conditions) was constructed, and is shown in Figure 4-1. The scenario concerns a P-3C Update I aircraft sent to investigate a SPA defined from a SOSUS station contact. The flight receives its pre-flight briefing at 1430 for a takeoff at 1830. Shortly before takeoff (at 1800), there may or may not be an update of the SPA resulting from analysis of data from a recently returned ASW flight in that area. Additionally, as the aircraft approaches its designated search area at 2300, it may receive another update on the submarine (based on intelligence data) which changes not only the SPA but also the search area as well. When the aircraft arrives on-station at 2300 and deploys its two environmental-recording sonobuoys and observes their data, it may either find the predicted conditions, a closely-related variant of those conditions (termed Variation "A") or a different variant (termed Variation "B"). The factorial combination of the three possible environmental conditions and the two possible SPA updates results in 12 distinct scenario evolutions, pictured as the 12 "leaves" of the Search pattern Selection scenario tree in Figure 4-1. Additional details of this scenario are given in Appendix A.

4.3 MISSION ACHIEVEMENT BENEFITS OF THE SONOBUOY PATTERN PLANNING AID

As discussed in Subsection 2.3 above, assessment of the possible mission achievement benefits from the Sonobuoy Pattern Planning aid requires the application of a mission achievement model to estimate the levels of aided and unaided mission achievement in each leaf of the scenario tree shown in Figure 4-1. Unaided mission achievement is defined as the mission achievement resulting from implementation of a search pattern planning decision made using current procedures, and aided mission achievement is defined as the mission

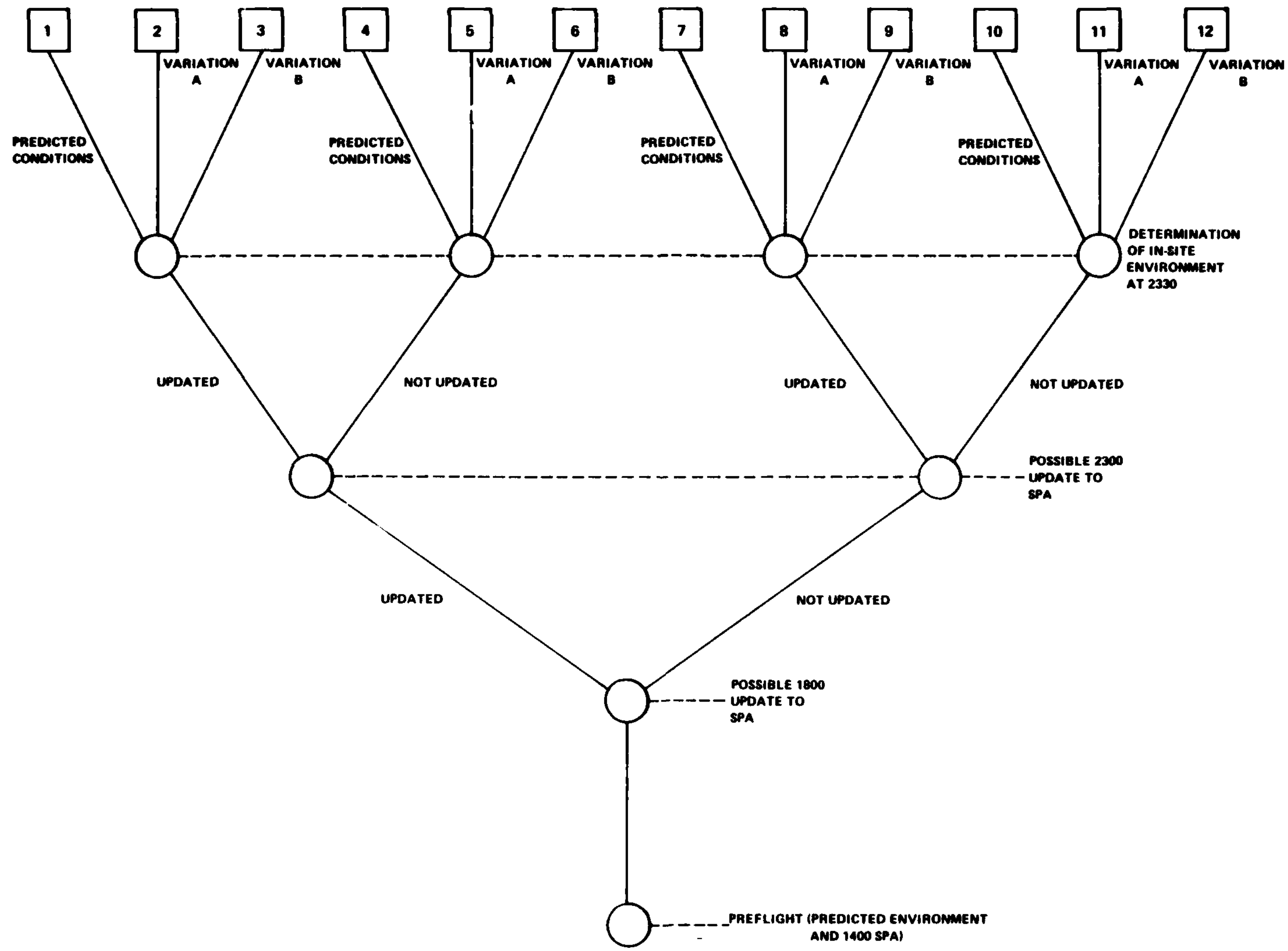

Figure 4-1. Scenario — Tree for Assessment of Sonobuoy Pattern Planning Decision Aid

achievement resulting from the implementation of the best possible decisions that could be made in the situation with information available to the ASW aircrew. In the case of the Sonobuoy Pattern Planning aid, these intuitive definitions of aided and unaided mission achievement proved easy to operationalize.

It was indicated in Subsection 4.2 that in current procedures, the initial sonobuoy pattern is selected at the ground- or ship-based support facilities and provided to the aircrew prior to takeoff. The initial pattern selected by the support facility is deployed by the ASW aircraft when it arrives on-station even if the measured in-situ environmental conditions are different from the predictions upon which the pattern was chosen. Moreover, it will also deploy the pre-selected pattern even if the SPA is updated, adjusting it only to center it in whatever new SPA is received. This procedure greatly simplifies the process of determining unaided mission achievement in each of the 12 scenarios in Figure 4-1. In the unaided condition, whatever pattern would be selected for the predicted environmental conditions and the original (i.e., 1400) SPA would be deployed in all scenario evolutions. Thus, once this pattern was determined, its mission achievement in all scenario evolutions could be computed as the values UMA_i.

The most natural manner in which to determine the unaided mission achievement is to exercise the same computer model used in the support facilities to select initial search patterns. In practice, different models are used at different facilities. One widely used program is named the Tactical ASW Sonar Decision Aid (TASDA), and is employed primarily at ground-based ASWOCS. It is thus likely that TASDA would be used to select initial search pattern in the scenarios under consideration here. TASDA is a large, complex Monte-Carlo simulation model of Air ASW search operations which is linked to an enumerative optimization algorithm. Given a set of possible pattern geometries, a range of allowable spacing, and a scenario for the search, it uses the Monte-Carlo simulation to calculate a variety of mission achievement criteria for each spacing and orientation of each pattern geometry. Alternatively, given a spe[illegible]ic pattern geometry, spacing and orientation and a scenario, it can compute that pattern's expected effectiveness on these same criteria. When used to select patterns, TASDA prints out all criteria values for all patterns, spacings, and orientation, and allows the ASWOC personnel to determine the pattern, spacing and orientation which promises to have the highest overall mission achievement. Thus, TASDA is not so much a search pattern selection program, as a general-purpose mission achievement model for Air ASW Search Planning.

Because of this, TASDA was used in three different ways in the assessment of mission achievement benefits for the Sonobuoy Pattern Planning decision aid. First, it was used to determine the decision that would be made in the unaided condition, i.e., to select the optimal pattern for the predicted environment and the 1400 SPA. Second, it was used to determine the mission achievement levels associated with that unaided decision in all 12 of the scenario evolutions shown in Figure 4-1. And third, it was used to determine the aided optimal pattern and associated levels of mission achievement for each leaf in the scenario tree.

TASDA produces as outputs from its Monte-Carlo model seven measures of mission achievement for a given pattern and scenario. These are the:

- Probability of detecting a submarine by at least one sonobuoy in the pattern (PD_1),
- Probability of detecting a submarine by at least two sonobuoys in the pattern (PD_2),
- Probability of detecting a submarine by at least three sonobuoys in the pattern (PD_3),
- Mean time from full deployment to first detection (MTFD),
- Mean time a contact is held on one sonobuoy during the life of the pattern (MHT_1),

- Mean time a contact is held on two sonobuoys during the life of the pattern (MHT_2).

- Mean time a contact is held on three sonobuoys during the life of the pattern (MHT_3).

In addition to these seven criteria supplied by TASDA, an eighth criterion was defined for each pattern: the amount of time required to deploy the pattern at a standard flight speed. Since no fleet-standard procedure exists for selecting an optimal pattern on the basis of TASDA output, a decision rule for this purpose was constructed in consultation with experienced ASW operations analysts. In practice, this rule takes into account only four criteria -- PD_1, MTFD, MHT_1, and time-to-deploy -- as application of the rule showed that in all cases an optimal pattern could be determined after examining only these four criteria.

The decision rule used to select optimal patterns from TASDA's mission achievement criteria is a hierarchical one. It considers multiple criteria, but only on a "satisfying" basis and only one at a time. If a given pattern geometry, spacing, and orientation "passes" a test on one criterion, it moves on to the next criterion; otherwise, it is removed from further consideration. At the point where only one alternative remains, the procedure is stopped and the remaining alternative is defined as optimal.

The first criterion considered is PD_1. This is because the initial pattern must have above all else a high probability of gaining some contact with the target. Any pattern having a PD_1 value within .05 of the highest PD_1 value recorded for any pattern in that given scenario evolution was considered to be "acceptable" on the PD_1 criterion; otherwise, it is considered unacceptable. In most cases, this reduced the number of patterns being considered by about 80 percent.

The next criterion considered was the time-to-deploy. Other things being equal (and all patterns with "acceptable" PD_1 values were about equal in detection capability), it is desirable to choose a pattern which can be deployed most quickly as an easy-to-deploy pattern leaves more on-station time for subsequent prosecution of the contact that is gained. Thus, any pattern not already rejected was considered to have an acceptable deployment time if its deployment time was within 30 minutes of the shortest deployment time recorded for any pattern still being considered. Otherwise, it was considered to have an unacceptable deployment time. In most cases, this step reduced the number of patterns under consideration to five or fewer.

The third criterion considered was MTFD. For patterns which have a high PD_1 and a reasonably low deployment time, those patterns which make contact quicker are better. Thus, any pattern still not rejected was considered to have an acceptable MTFD if its MTFD was within five minutes of the lowest MTFD for any pattern still being considered. Otherwise, it was considered unacceptable. This step usually narrowed the number of patterns to one. In a few cases, however, a fourth level of selection was required.

This fourth criterion considered was the MHT_1. This is important because the longer a contact is held by a given sonobuoy, the more likely it is that contact investigation patterns can be selected and deployed in such a way as to maintain the continuity of the contact. Any pattern still not rejected was considered to have an acceptable MHT_1 if it was within five minutes of the highest MHT_1 for any pattern still under consideration. Otherwise, it was considered unacceptable. In no case was more than one pattern remaining after this step.

This procedure was used together with TASDA to determine the optimal pattern for the unaided condition, and for each of the 12 scenario-evolutions of the aided condition. TASDA was then used to determine the mission achievement criteria values that the unaided decision would yield in each of the 11 remaining leaves on the scenario tree. The mission achievement criteria values for the unaided condition are shown in Table 4-2 and the mission achievement

Table 4-2. TASDA Results for Unaided Search Pattern Planning

	ENVIRONMENTAL CONDITIONS			
FINAL SPA	CRITERIA	PREDICTED	VARIATION "A"	VARIATION "B"
1400	PD_1	0.75	0.77	0.61
	Deployment Time	160.00	160.00	160.00
	MHT_1	67.00	56.00	60.00
	MTFD	58.00	65.00	71.00
1800	PD_1	0.98	0.99	0.85
	Deployment Time	160.00	160.00	160.00
	MHT_1	64.00	62.00	60.00
	MTFD	40.00	48.00	60.00
2300	PD_1	0.97	0.92	0.84
	Deployment Time	160.00	160.00	160.00
	MHT_1	61.00	62.00	60.00
	MTFD	47.00	47.00	67.00

criteria values for the aided conditions are shown in Table 4-3. In both of these tables deployment time, mean time to first detection, and mean holding time are all measured in minutes. Only nine combinations of SPAs and environmental conditions are shown. This is because for mission achievement purposes only the *final* SPA matters -- the scenarios having SPA updates at 1800 *and* 2300 yield identical mission achievement values to those having SPA updates at 2300 only. It should also be noted that the specific patterns used in the selection process are not listed because they are classified.

The value of the four criteria shown in Tables 4-2 and 4-3 were then combined to produce values of AMA_i and UMA_i for each of the 12 scenario evolutions shown in Figure 4-1. A combination function was devised that incorporated all four criteria used in hierarchical decision rule. This combination function is the ratio of two effectiveness terms. The first term is given by:

$$(PD_1 \cdot MHT_1)$$

and essentially computes the "power" of the pattern by multiplying the level of PD_1 obtained for the pattern by the expected or mean time each contact will be held. The second term is given by:

$$(\text{MTFD} + \text{Deployment Time})$$

and gives the "cost" of the pattern, by computing the total expected number of minutes that must be expended in gaining an initial contact. Obviously, the larger the first term becomes, the *better* the search pattern is, and the larger the second term becomes, the *worse* the search pattern is. Thus, the overall combination rule is given simply by:

$$MA = \frac{(PD_1 \cdot MHT_1)}{(\text{MTFD} + \text{Deployment Time})} \qquad (4.1)$$

If values from PD_1, time-to-deploy, MHT_1, and MTFD are taken from Table 4-2 and substituted into equation 4.1, then the value produced is one of the UMA_i. If they are taken from Table 4-3, the value produced is one of the AMA_i.

Table 4-3. TASDA Results for Aided Search Pattern Planning

	ENVIRONMENTAL CONDITIONS			
FINAL SPA	CRITERIA	PREDICTED	VARIATION "A"	VARIATION "B"
1400	PD_1	0.75	0.76	0.61
	Deployment Time	160.00	128.00	160.00
	MHT_1	67.00	52.00	60.00
	MTFD	58.00	65.00	71.00
1800	PD_1	0.96	0.96	0.99
	Deployment Time	24.00	16.00	148.00
	MHT_1	86.00	97.00	64.00
	MTFD	17.00	23.00	81.00
2300	PD_1	0.92	0.91	0.80
	Deployment Time	91.00	91.00	128.00
	MHT_1	64.00	60.00	60.00
	MTFD	35.00	42.00	50.00

Table 4-4 indicates the values of AMA_i, UMA_i, (AMA_i/UMA_i), and P_i for each of the 12 leaves in the scenario tree used in this benefit assessment procedure. All the values of the AMA_i/UMA_i ratio indicate moderate improvements in performance of aided over unaided mission achievement except those for scenario evolutions four and five. In these two cases, the improvement in aided over unaided performance approaches an order of magnitude. The size of the ratio in those two cases is sufficiently great as to warrant some additional discussion.

There is a great variability in the time required to deploy the various initial search patterns. One pattern with an extremely short deployment time can only be used in certain circumstances. Those circumstances were not present in the conditions upon which the unaided decision was based (i.e., 1400 SPA and predicted environmental conditions); they did obtain in scenario evolutions four and five. Because the deployment time of this particular pattern is less than that of any of the others by more than an order of magnitude, the ability to determine that this pattern is applicable in these two scenarios resulted in a corresponding order-of-magnitude increase in mission achievement.

Table 4-4 also gives the values of the product $P_i\left(\frac{AMA_i}{UMA_i}\right)$ which, according to equation 2.1 above, are summed to produce the $\Delta\overline{MA}$. For the Sonobuoy Pattern Planning decision aid this sum is 1.871, indicating a more than 87% increase in mission achievement (above the 'no-change' level of 1.0) is possible.

It should be noted, however, that this $\Delta\overline{MA}$ value indicates only the difference between current (unaided) and optimal decision-making performance. It is not the level of increase expected from the decision aid for Search Planning as that performance gain is strictly dependent on the aiding algorithm ultimately implemented. However, this sizable 'room for improvement' in Search Pattern Planning is obviously indicative of the need for a decision aid of the type considered here.

Table 4-4. Comparison of Aided and Unaided Search Pattern Planning

	Scenario(I)											
	1	2	3	4	5	6	7	8	9	10	11	12
AIDED MISSION ACHIEVEMENT (AMA_i)	.471	.413	.272	2.44	2.381	.282	.470	.411	.272	.232	.201	.163
UNAIDED MISSION ACHIEVEMENT (UMA_i)	.287	.276	.222	.315	.301	.232	.287	.276	.223	.232	.196	.163
RATIO OF $\left(\frac{AMA_i}{UMA_i}\right)$	1.64	1.50	1.22	6.39	7.91	1.21	1.64	1.49	1.22	1.00	1.03	1.00
PROBABILITY OF SCENARIO (P_i)	.02	.012	.008	.08	.048	.032	.08	.048	.032	.32	.192	.128
$P_i\left(\frac{AMA_i}{UMA_i}\right)$	.033	.018	.010	.511	.380	.039	.131	.072	.039	.32	.19	.128

4.4 WORKLOAD REDUCTION BENEFITS OF THE SONOBUOY PATTERN PLANNING DECISION AID

After the direct or mission achievement benefits of the sonobuoy Pattern Planning decision aid were assessed, the procedures outlined in Subsections 2.4 and 2.5 for assessing the indirect or workload reduction benefits were applied to that aid design. The first step in this procedure was the identification of the specific functions which the TACCO must perform during the portion of the mission in which the decision aid would be used. Given the scenario tree constructed for the assessment of this aid, the relevant TACCO functions were those required for the development and deployment of an initial search pattern. A total of 11 such functions were identified. They are listed in Table 4-5 along with brief descriptions of each. More detailed descriptions of these functions can be found in Zaklad (1981).

In the second step, the order in which these functions are performed in each scenario evolution was determined. This was done separately for current (unaided) procedures, and for the procedures which would apply if the decision aid were present. Next, estimates of the times within the mission at which each function would be performed were made to define a timeline of TACCO functions for each scenario and aiding condition. An analysis of the scenario tree in Figure 4-1 showed that there were actually only four unique sequences of TACCO functions -- those arising from the various combinations of SPA updates. This is because the TACCO performs exactly the same functions in the same order for deploying and recording the results from the environmental (BT and AN) sonobuoys, regardless of whether the results indicate the predicted propagation conditions or some variation. Thus, only four timelines were required to represent TACCO functions in the 12 scenario evolutions shown in Figure 4-1.

After these timelines were developed, generalized pidgin-HOPROC sequences representing the detailed actions required by the TACCO to fulfill each function listed in Table 4-5 were then constructed. Separate pidgin-HOPROC sequences were developed for those functions which would be performed differently

Table 4-5. TACCO Functions in Search Pattern Planning

ENTER-OPERATOR-PREFERENCES -- enter restrictions on geometries, sonobuoy types, and/or sonobuoy locations that can be considered.

DISPLAY-SONOBUOY-LOCATION -- calculate and enter an Multipurpose Digital Display (MDD) the locaton of a given sonobuoy and/or pattern.

DISPLAY-SPA -- enter and display on MDD current Submarine Probability Area, deleting from MDD previous SOA if necessary.

LAUNCH-SONOBUOY -- initiate sequence of events necessary to deploy a sonobuoy.

SELECT-OCEANOGRAPHIC-SONOBUOYS -- determine location for deployment of Bathythermal and Ambient Noise recording sonobuoys, and initinate sequence of events necessary to deploy them.

REVIEW-OCEANOGRAPHIC-SONOBUOYS -- obtain data from BT and AN sonobuoys, verify their accuracy, analyze them, and take any action necessary to modify search pattern.

OBTAIN-SEARCH-AREA -- determine that the ASW aircraft has arrived at the specified search area.

VERIFY-ON-STATION -- determine and verify that the ASW aircraft has begun its on-station period.

CONSULT-DECISION-AID -- interact with the Sonobuoy Pattern Planning decision aid to select an initial search pattern geometry, spacing, orientation, location, sonobuoy type, and setting.

PREPARE-AIRCRAFT-TO-DEPLOY-SONOBUOY -- generate fly-to-points necessary to position ASW aircraft at next sonobuoy deployment location, select and set sonobuoy to be deployed once the fly-to-point has been captured.

with the Sonobuoy Pattern Planning decision aid than with the current procedures. One function -- Consult-Decision-Aid -- obviously applies only to the aided case and requires no TACCO actions whatsoever in the unaided condition. A full listing of the HOPROC representation of these 11 functions can be found in Zaklad (1981). The specific characteristics of the four distinct groups of scenarios for which timelines were constructed applied to the pidgin-HOPROC sequences for the 11 search pattern planning functions and the four timelines to create two specific pidgin-HOPROC sequences for each of the four scenario groups. One sequence gave the unaided TACCO actions, and the other the aided TACCO actions. Appendix C presents the timelines and pidgin-HOPROC sequences for each of the four groups of scenarios in this scenario tree, to demonstrate the process by which scenario-specific aided and unaided timelines are constructed and translated into aided and unaided pidgin-HOPROC sequences for a given scenario tree.

The 13 workload measures presented in Table 2-1 were then applied to each of these pidgin-HOPROC sequences by a rating panel of Analytics' human factors and ASW analysts with results as indicated in Table 4-6. The workload measure combination formula given in Equation 2.3 was then applied to the values in each row of Table 4-6 to produce values for UWL_i and AWL_i. Table 4-7 shows these values, together with the AWL_i-UW'_i differences, the P_i, and the $P_i(AWL_i$-$UWL_i)$ product. These values were then summed according to Equation 2.2 to produce $\Delta\overline{WL}$ -- the expected levels of workload reduction in the aided condition. For this scenario tree, this expected workload reduction value was 18.4%, indicating a moderate decrease in operator workload with the Sonobuoy Pattern Planning decision aid. While the direction of this change -- a *decrease* in operator workload -- is encouraging, its absolute magnitude is small. This is primarily because the current operator workload levels are already low in this mission phase. The initial portion of the on-station search phase of the Air ASW mission is probably the least busy part of the mission for the aircrew, as reflected in the zero values in the columns of Table 4-6 representing the interruption workload measures. This suggests that the level of work

Table 4-6. Workload Rating Sums for Four Groups of Search Planning Scenario Evolutions

SCENARIO EVOLUTIONS WITH:		COGNITIVE					PSYCHO-MOTOR		MOTOR		INTERACTIONAL			
		PLD	PRD	CLC	IPC	IAC	TBM	WTG	BPF	KEF	IFQ	IMG	CFQ	CMC
NO SPA UPDATES	AIDED	0	0	2	235	274	1	0	54	143	0	0	1	1
	UNAIDED	0	0	1	209	257	1	8	67	103	0	0	1	1
SPA UPDATE AT 2300 ONLY	AIDED	0	0	2	256	305	1	0	54	168	0	0	1	1
	UNAIDED	0	0	1	228	291	14	8	83	114	0	0	1	1
SPA UPDATE AT 1800 ONLY	AIDED	0	0	2	250	296	1	0	56	170	0	0	1	1
	UNAIDED	0	0	1	219	285	12	8	89	147	0	0	1	1
SPA UPDATE AT 1800 and 2300	AIDED	0	0	2	271	327	1	0	56	195	0	0	1	1
	UNAIDED	0	0	1	236	319	25	8	105	158	0	0	1	1

Table 4.7. Comparison of Aided and Unaided Search Pattern Planning

	Scenario(i)											
	1	2	3	4	5	6	7	8	9	10	11	12
UWL_i	-17.08	-17.08	-17.08	-19.08	-19.08	-19.08	-31.12	-31.12	-31.12	-31.83	-31.83	-31.83
AWL_i	-28.80	-28.80	-28.80	-31.53	-31.53	-31.53	-32.99	-32.99	-32.99	-35.723	-35.72	-35.72
$AWL_i - UWL_i$	-11.72	-11.72	-11.72	-12.45	-12.45	-12.45	-1.87	-1.87	-1.87	-3.89	-3.89	-3.89
P_i	.02	.012	.008	.08	.048	.032	.08	.048	.032	.32	.192	.128
$P_i (AWL_i - UWL_i)$	-.23	-.14	-.09	-.99	-.60	-.40	-.15	-.09	-.06	-1.24	-.75	-.50
$P_i (UWL_i)$	-.34	-.21	-.14	-1.53	-.92	-.61	-2.49	-1.49	-.99	-10.18	-6.11	-4.07

is sufficently low that every task during this period of time can be performed as the need arises. Thus with the workload levels already low, no excessive reduction in operator workload can be possible.

5. BENEFIT ASSESSMENT OF THE ATTACK PLANNING DECISION AID

This section presents the application of the benefit assessment methodology outlined in Section 2 to a second Naval Air ASW decision aid, the Attack Planning decision aid. The design for this aid is taken from Zachary (1980b), where it was developed in response to the high priority derived for the Attack Planning decision situation. Subsection 5.1 reviews the overall structure and function of this decision aid, and Subsection 5.2 describes the scenario tree constructed for its benefit assessment. Subsection 5.3 presents the results of applying the mission achievement gain portion of the benefit assessment methodology to the Attack Planning aid, and Subsection 5.4 presents the results of applying the operator workload reduction portion of the benefit assessment methodology to it.

5.1 THE ATTACK PLANNING DECISION AID

After the ASW aircraft gains initial contact with a hostile submarine, the TACCO attempts to reduce the uncertainty in his knowledge of the submarine's location, depth, course, and speed to the point that an attack can be effectively placed against the submarine. The Attack Planning phase of the mission commences at the time the TACCO determines he has obtained a direct path contact with the submarine, because it is at this point that the submarine is first isolated to a specific well-defined and relatively small area of ocean. The prosecution of the contact from this point involves the deployment of additional passive sonobuoy patterns, the possible deployment of active sonobuoy patterns, the possible deployment of some combination of active and passive sonobuoy patterns, and the coordination of Magnetic Anomaly Detection (MAD) information with acoustic sensor information. Where possible, other sensor data such as FLIR and radar are also utilized. Once the first active sonobuoy is deployed and sounded or "pinged," the submarine is likely to become alerted to the presence of the ASW aircraft and initiate evasive maneuvers. Thus, as soon as active sonobuoys are deployed it is necessary to bring the prosecution of the contact to a swift resolution. The TACCO may deploy a weapon against the target as soon as his degree of certainty in the location, course, depth, and speed of the submarine fulfills one of the several fleet-defined criteria for attack.

The decision aid for Attack Planning serves two general functions. First, it automates some of the information processing currently required of the TACCO, and second, it helps speed the process by which one or more attack criteria are gained and a weapon is deployed. Specifically, the aid assists the TACCO in gaining attack criteria and in formulating the optimal tactics for an attack on the hostile submarine. The aid has five primary features:

- *assistance in gaining attack criteria* -- prior to the attainment of attack criteria, the aid suggests to the TACCO specific tactics that could speed the process of gaining attack criteria, provides automatic display of data on the targets' possible location, and assists the TACCO in establishing target fixes,

- *automation of attack criteria* -- the aid automatically interrogates the incoming sensor data and TACCO-supplied judgemental data and continuously compares these data to fleet-defined attack criteria; when attack criteria are gained the aid immediately notifies the TACCO,

- *optimization of attack tactics* -- after attack criteria are gained, the aid suggests the optimal location and time for an attack on the target given the present location and the motion capabilities of the submarine,

- *optimization of weapon selection* -- for the attack to be placed, the aid suggests the type of weapon to be used and the optimal engagement setting for it,

- *interface to pilot and navigator* -- if the TACCO accepts the attack tactics (i.e. location and time) suggested by the aid, or if he enters alternate tactics of his own selection, the aid calculates fly-to-points and provides steering (navigational) commands to the pilot.

The Attack Planning aid alerts the aircrew when attack criteria have been gained, recommends optimum weapon settings, determines optimal weapon placement, and provides aircraft navigation commands needed to deploy the weapon. The aid is activated by the TACCO when he has gained a direct path contact with the submarine.

The attack planning aid utilizes several inputs to produce the outputs listed above. In specific, it requires data on the:

- characteristics and capabilities of the ASW aircraft and its weapons,
- estimated capabilities of the submarine,
- atmospheric and oceanographic conditions,
- type, location, depth, and setting of currently deployed sonobuoys,
- history of the contact with the target being attacked, and
- overall tactical situation, including fuel and time on-station remaining for the ASW aircraft, the relative location of any friendly areas threatened by the submarine, and the offensive capabilities of the submarine.

All of these inputs can be obtained from either a prestored data base or from other computer programs in the ASW aircraft.

The aid also requires several inputs from the TACCO. At various times the TACCO must enter his "best-guess" estimate of the submarine's actual location and/or select a specific location at which to establish a fix when the aid's calculations shows that there are two or more possible fixes.

The description of this aid given above contains all the informtion on it needed to assess its potential benefits in the current Naval Air ASW environment. Additional details on the algorithmic structure of the Attack Planning decision aid can be found in Section 5 of Zachary (1980b).

5.2 SCENARIO TREE FOR BENEFIT ASSESMENT OF THE ATTACK PLANNING AID

To simplify the construction of the scenario tree for Attack Planning, the core of the scenario was taken directly from the scenario constructed for the assessment of the Sonobuoy Pattern Planning decision aid. Thus, the basic Attack Planning scenario was considered to be simply a later evolution of the scenario described in Appendix A. This allowed all of the details developed for the assessment of the Sonobuoy Pattern Planning aid to be utilized again in the assessment of the Attack Planning aid.

Although attack planning is affected by a great many contingencies, it was necessary to limit the number considered in order to keep the benefit assessment procedure at a managable level. The three general contingencies considered to affect attack planning decision making are:

1) The number of passive sonobuoys remaining on-board the aircraft when direct path contact with the target is obtained,

2) The amount of on-station time remaining when direct path contact is obtained, and

3) The possibility of a relief platform arriving at the end of the ASW aircraft's on-station period.

The number of passive sonobuoys with which the TACCO may prosecute the contact during Attack Planning has an obvious constraining effect on his decision-making processes. A low passive sonobuoy inventory can prevent the application of many types of patterns, it can restrict the number of patterns that can be applied to refine the target's location, course, depth, and speed, and it can force an early recourse to active prosecution. The amount of remaining on-station time has a similiar constraining effect. If only a small amount of time remains, the TACCO is able to deploy only a limited number of patterns, and again may be forced to attempt active prosecution earlier than might otherwise be desirable. The presence or absence of a relief platform also constrains TACCO decision making by defining whether or not the TACCO must place an attack on the submarine. If a relief platform is expected, the TACCO has the option of handing off the contact to it, but if no relief platform is due, then the TACCO must either destroy the target or permit its escape.

A scenario-tree incorporating these three factors (passive sonobuoy inventory, remaining on-station time, and relief platform availability) was constructed and is shown here in Figure 5-1. An analysis of possible mission evolutions from the beginning of on-station to the attainment of a direct path contact suggested that a representative range of times available for attack planning functions was from as much as 2 hours and 15 minutes to as little as 45 minutes. These end points were used as two alternative events in the evolution of this mission, as indicated in Figure 5-1. The ASW aircraft arrives on-station at 2330 and gains initial contact at 0100; in one case it obtains a direct path contact with the submarine at 0145, and in the other obtains a direct path contact at 0315. Thus, given the expected end of the on-station period the 0400, there is either 2 hours and 15 minutes or 45 minutes remaining for Attack Planning.

Independent of the amount of time spent obtaining direct path contact, the aircraft may have a relatively large remaining inventory of passive sonobuoys (20) or a relatively small remaining inventory of passive sonobuoys (8). Thus, for both branches of the scenario-tree at this point, subsequent evolution of the mission may involve the use of a small or a large inventory of remaining passive sonobuoys. And also independent of the number of sonobuoys or the amount of on-station time remaining, a relief platform may or may not be expected at the end of this mission. Thus, each branch in the scenario tree at this point has two possible evolutions, one in which the TACCO expects a possible hand-off of the target, and one in which he does not. A total of eight distinct scenario evolutions therefore arise from these three contingencies, as shown in Figure 5-1. The probabilities of each of these evolutions occurring, and additional details on this scenario tree are presented in Appendix B.

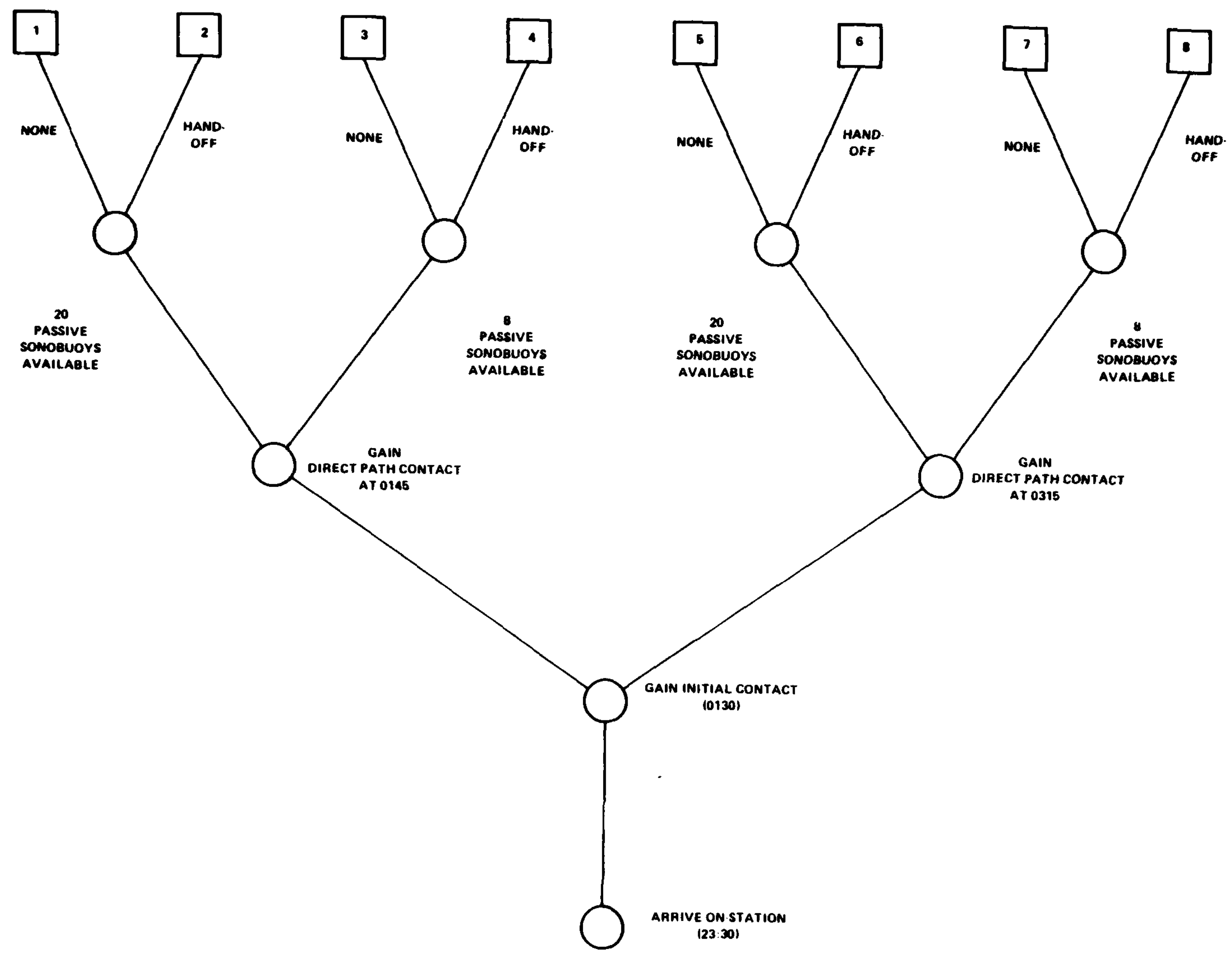

Figure 5-1. Scenario — Tree for Assessment of Attack Planning Decision Aid

5.3 MISSION ACHIEVEMENT BENEFITS OF THE ATTACK PLANNING DECISION AID

As discussed in Subsections 2.3 and 4.3, the assessment of the mission achievement benefits of the Attack Planning decision aid requires the use of a model which can translate aided and unaided decisions into appropriate measures of their results in the mission. The selection of such a mission achievement model for attack planning decision making proved to be a significant problem, primarily because the range of TACCO decisions that are relevant to attack planning is so very broad. During this mission phase the TACCO makes decisions concerning not only the selection and time-of-deployment of sonobuoy patterns, but also concerning the use of other sensors (e.g., MAD), the coordination of sensors, the possible location, course, depth, and speed of the submarine, and weapon-related tactics. Each of these decisions is addressed in some way by the decision aid and each of them affects attack planning mission achievement. Thus, an acceptable mission achievement model must consider all of these decisions and their relationship to mission achievement. Such a model would therefore be extremely complex. Unfortunately, no off-the-shelf attack planning mission achievement model which even approached the desired level of detail was available. This made it necessary to build a mission achievement model exclusively for the benefit assessment of this aid. Given the potential complexity of such a model, however, great care had to be taken to ensure that the model-construction task did not get out of hand.

To keep the complexity of the model and benefit assessment procedure at a level of detail appropriate for the early design evaluation stage involved here, it was decided to restrict the kinds of decision that the model would consider. In particular, the model was restricted to considering only the relationship between mission achievement and sonobuoy and weapon use. That is, it was decided *not* to include in the model any aspect of the use of sensors other than sonobuoys, such as MAD, or FLIR. This restriction on the model limited in turn the portions of the decision aid that could be assessed for mission achievement benefits. The benefits arising from features of the aid which addressed the correlated use of different sensors, and the attainment of attack

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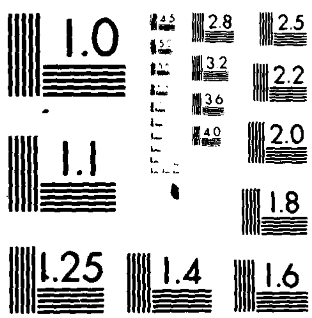

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criteria through the use of non-acoustic sensors could not be measured with the use of a mission achievement model that considered only acoustic sensors. Therefore, the mission achievement gains demonstrated by the Attack Planning aid must be viewed as only tentative. It is reasonable to expect that the consideration of the remaining portions of the aid would lead to a still higher increase in mission achievement.

Perhaps more than any other decision situation, the Attack Planning decision situation requires the careful coordination of a series of decisions to achieve a single goal event--a successful attack on the submarine. It is therefore necessary to consider the impact of a *full sequence of TACCO actions and decisions* on mission achievement in a given Attack Planning scenario evolution. To accomodate this need, the mission achievement model was implemented as an interactive computer program, with the computer simulating the movement of a hostile submarine and the data that would be presented to a TACCO at his work station, and the user acting as TACCO and inputting his decisions to the program accordingly. The full details of this program and its various component models are given in Appendix D.

The attack planning mission achievement model provides four basic measures of attack planning mission achievement. The first (and by far the most important) is the probability of killing the submarine, denoted P_k. The second is the amount of time expended between the start of attack planning (i.e., the time at which a direct path contact is gained) and the placing of an attack on the submarine, denoted T. The third is the number of passive sonobuoys utilized in the attack planning process, denoted S. The fourth is the number of minutes spent in active prosecution of the submarine, denoted A. These last three measures are included to allow consideration some of the more subtle benefits of the decision aid. It is obviously important for the decision aid to increase the expected value P_k. But beyond this, however, it is also desirable for the aid to help the TACCO place an attack more quickly (reduce T), utilize fewer resources (reduce S), and minimize the duration of active prosecution in which the submarine is alerted and undertakes evasive action (reduce A).

The mission achievement model described in Appendix D was initially exercised for each of the eight unaided scenario evolutions shown in Figure 5-1. The results of these simulations in terms of P_k, A, S, and T are shown in Table 5-1.

Table 5-1. Unaided Mission Achievement in Attack Planning

	SCENARIO$_{(i)}$							
MISSION ACHIEVEMENT MEASURES	1	2	3	4	5	6	7	8
P_k	.68	.45	.32	.70	.45	.65	.22	.19
T	50	43	53	45	28	33	43	42
S	11	6	8	8	8	7	8	8
A	6	10	7	10	4	7	4	7

Two changes were then made in the model to simulate the aided condition. The first change, made to simulate the aid's assistance in establishing target fixes and in post-processing and correlating data from different acoustic sensors, was simply to reduce the size of the error term included in the simulated sonobuoy returns. An analysis of the aid's likely level of performance suggested that the sonobuoy error reported to the TACCO should be reduced by a factor of 2. The second change was made to emulate the assistance the attack planning aid would provide in selecting a weapon, setting, and launch point. Rather than having the TACCO select the weapon, setting, and launch point as in the unaided condition, the program was modified to have the TACCO simply enter his best estimate of the target's location, course, depth, and speed at the time of desired weapon deployment. The program then determined the optimal weapon, setting, and deployment location. With these changes entered, the model was again exercised for each of the eight scenario evolutions shown in Figure 5-1. The results of these simulations in terms of P_k, A, S, and T are shown in Table 5-2.

Table 5-2. Aided Mission Achievement in Attack Planning

	SCENARIO$_{(i)}$							
MISSION ACHIEVEMENT MEASURES	1	2	3	4	5	6	7	8
P_k	.92	.94	.95	.92	.92	.95	.92	.67
T	28	24	33	27	39	33	29	29
S	5	5	6	6	7	7	6	6
A	5	6	7	8	5	[illegible]	6	7

It was next necessary to combine the four measures of mission achievement into values of AMA_i and UMA_i for each scenario. Before a combination rule was devised, four properties which it must exhibit were specified. The first such property was that it be dominated by P_k. No combination of other factors should be able to compensate for the failure to kill the submarine, just as no combination of other factors should be able to diminish the desirability of killing it. The second required property was that the effects of T and S should be exhibited primarily at the margin. That is, for a given P_k the effect of the total time (T) to attack and the number of sonobuoys (S) used should become important only as they near their limiting values. Thus, if R is the remaining on-station time when Attack Planning begins, then T should become an important factor only when it nears R. Similarly, if I is the total passive sonobuoy inventory when Attack Planning begins, then S should become an important factor only as it nears I. A should have a similar effect, but since there is no maximum possible active time, its effect should merely become more pronounced as A increases in value. The third property is that, other things being equal, the value of T should be more important than the value of S. This is because there are other sensors which could be used to continue the mission even if all sonobuoys are gone, but once the on-station time has expired there is no way to compensate for it. The fourth property is that the combination rule should allow some measurable mission achievement even when P_k is 0 (i.e., when the torpedo completely misses the submarine or when an attack is not placed).

The combination rule which possesses all these properties is given by:

$$MA = \left(\frac{\sqrt{3}}{\sqrt{3+A}}\right) \cdot ((\ln 100P_k)+1) \cdot \left(1-\left(\frac{T}{R+1}\right)^2\right) \cdot \left(1-\left(\frac{S}{I+1}\right)^4\right) \qquad (5.1)$$

The first term allows the value of A to "discount" the value of the remainder of the expression in a way which is minor when A is near 0 but which increases as A gets large. The constant of 3 was empirically selected as that value for which an active period of more than nine minutes has the effect of reducing the value of the overall expression by 50 percent. This time of nine minutes was felt to be the expected median active prosecution period. The second term clearly dominates the entire formula, as was desired, and causes the overall MA to increase monotonically with P_k, while providing added emphasis to gains in the 0-.6 range. This reflects a desire to increase P_k into the region where there is a sizable likelihood that the submarine will actually be destroyed. The third and fourth terms are also "discounting" terms, based on T and S. As T and S each become closer to their physical limits (R and I respectively), the value of the term where they appear has an increasingly pronounced effect. The exponents were included simply to limit the effect of these terms to the cases when the limits are very nearly reached. The difference in exponents reflects giving more weight to T than to S.

The values for P_k, A, T, and S were taken from Tables 5-1 and 5-2 along with the appropriate values for R and I (which depend on the scenario evolution involved) and substituted into equation 5.1 to generate the values of UMA_i and AMA_i for the Attack Planning decision aid. These values were then substituted along with the P_i for the Attack Planning scenario evolutions into equation 2.1 to generate the value of $\Delta\overline{MA}$ for this aid. The values of UMA_i, AMA_i, the AMA_i/UMA_i ratios, the P_i, and the $P_i(AMA_i/UMA_i)$ products are shown in Table 5-3. All the values of the (AMA_i/UMA_i) ratio in Table 5-3 indicate a large increase in mission achievement from the unaided to the aided condition. The increase is especially large in those scenario evolutions where on-station time is short and/or the sonobuoy inventory is low, suggesting that there is substantial room for improvement in decision making in such highly constrained Attack Planning situations. The values of the product $P_i(AMA_i/UMA_i)$ are also given in Table 5-3. When these values are summed according to equation 2.1 above, an overall value of 3.036 is obtained for $\Delta\overline{MA}$, indicating a twofold increase in mission achievement is possible with a comprehensive decision aid for Attack Planning. This increase becomes even more impressive when it is recalled that the aspects of the decision aid which affect sensors other than acoustic sonobuoys are not included in the 203 percent potential change in mission achievement levels. As with the Sonobuoy Pattern

Table 5-3. Comparison of Aided and Unaided Attack Planning Mission Achievement

	Scenario(i)							
	1	2	3	4	5	6	7	8
UMA_i	2.41	2.06	0.79	0.85	1.93	1.36	0.13	0.22
AMA_i	3.23	3.09	2.30	2.22	0.88	1.46	1.54	1.37
AMA_i/UMA_i	1.34	1.50	2.91	2.61	0.46	1.07	12.08	6.14
P_i	0.036	0.144	0.024	0.096	0.084	0.336	0.056	0.224
$P_i(AMA_i/UMA_i)$	0.048	0.216	0.070	0.251	0.038	0.361	0.676	1.38

Planning aid assessment, it should be kept in mind here that this value of $\Delta\overline{MA}$ indicates only the *potential* gain, or 'room for improvement' in Attack Planning decision making, not the *actual* improvement expected from the Attack Planning decision aid. However, the large $\Delta\overline{MA}$ value clearly suggests that an Attack Planning decision aid can serve a valuable function.

5.4 WORKLOAD REDUCTION BENEFITS OF THE ATTACK PLANNING DECISION AID

After the direct or mission achievement benefits of the Attack Planning decision aid were assessed, the procedures outlined in Subsections 2.4 and 2.5 for assessing indirect or workload reduction benefits were applied to this aid design. The first step in the procedure was the identification of the specific functions which the TACCO must perform during the Attack Planning portion of the mission. A total of 19 such functions were identified; they are listed in Table 5-4 along with brief descriptions. More detailed descriptions of several of these functions can be found in Zaklad (1981).

In the second step, the order in which these functions are performed in each evolution in the scenario tree (Figure 5-1) was determined. This was done separately for the aided and unaided procedures. Next, estimates were made of the times within the mission at which each function would be performed, to define a timeline of TACCO functions for each scenario evolution and aiding condition. Unlike search planning where only four timelines were needed to describe TACCO procedures in 12 scenario evolutions, separate timelines were required for each of the eight separate evolutions of the Attack Planning scenario tree.

After these timelines were developed, generalized pidgin-HOPROC sequences were constructed to represent the specific TACCO actions required to fulfill each function listed in Table 5-4. Separate pidgin-HOPROC sequences were developed for those functions which would be performed differently with the Attack Planning decision aid than with the current equipment. Again unlike the Search Planning situation, no separate function for consulting the decision aid was

TABLE 5-4. TACCO FUNCTIONS IN ATTACK PLANNING

DETERMINE TARGET INITIAL LOCATION -- Upon attainment of direct path contact, delimit area of ocean in which submarine must be located.

DETERMINE PATTERN TYPE -- Select geometry and location of next sonobuoy pattern to be deployed.

DISPLAY SONOBUOY LOCATION -- Enter selected pattern geometry and location onto MDD and provide steering commands to pilot for pattern deployment.

PREPARE AIRCRAFT TO DEPLOY SONOBUOY -- Initiate sequence of aircraft events necessary to allow aircraft to release sonobuoy at desired time and location.

VERIFY AIRCRAFT POSITIONED TO LAUNCH POINT -- Check navigation data/displays to ensure that proper steering commands for sonobuoy or weapon deployment are being followed.

LAUNCH SONOBUOY -- Initiate sequence of events to drop sonobuoy when desired location has been attained.

MONITOR MDD -- Attend MDD for changes to and/or display of new sensor information.

DETERMINE TARGET FIX -- Enter new target fix onto MDD.

POSITION AIRCRAFT FOR MONITORING -- Select and implement optimal flight altitude and pattern for monitoring of desired sensor suite.

DETERMINE TARGET COURSE AND SPEED -- Review sensor data and target fixes on MDD to establish estimate of target course and speed.

OBSERVE MAD -- Monitor MDD when expecting possible MAD contact.

ADJUST PATTERN/TACTICS FOR MAD -- After MAD contact, adjust flight path of aircraft to optimize likelihood of additional MAD contacts.

TABLE 5-4. TACCO FUNCTIONS IN ATTACK PLANNING (continued)

CORRELATE TARGET FIXES -- Assess sequence of target fixes and course/speed estimates for anomalies and possible erroneous fixes.

DETERMINE ATTACK CRITERIA -- Assess target fixes, course/speed estimates, and other sensor data to determine if criteria for attack have been met.

DETERMINE WEAPON TYPE -- Select type of weapon to be used against target once attack criteria have been met.

PREPARE WEAPON -- Initiate sequence of aircraft events reqired for weapon deployment.

DETERMINE WEAPON RELEASE POINT -- Calculate flight path and release point which will optimize weapon's effectiveness.

RELEASE WEAPON -- Initiate sequence of aircraft events required to launch weapon once release point has been attained.

necessary because the aid's use is integrated into the performance of functions currently required of the TACCO in Attack Planning. A full listing of the pidgin-HOPROC for these TACCO functions can be found in Zaklad (1981).

The specific characteristics of the eight distinct scenario evolutions in the scenario tree were then combined with the pidgin-HOPROC representations of the TACCO functions and the TACCO function timelines to create two specific pidgin-HOPROC sequences (aided and unaided) for each of the eight scenario evolutions.

The 13 workload measures presented in Table 2-1 were applied to each of these pidgin-HOPROC sequences by a rating panel of Analytics' human factors and ASW analysts, with results as indicated in Table 5-5 for the unaided condition and Table 5-6 for the aided condition. As can be seen in Tables 5-5 and 5-6, the overall levels of operator workload are much higher in Attack Planning than they are in Search Pattern Planning (see Table 4-6). In particular there are higher levels of cognitive workload, as well as many more interruptions in this mission phase. This observation is consistent with the results obtained in Zachary (1980b), showing that the Attack Planning decision situation had the highest information-processing load of any of the six decision situations considered there.

The workload combination formula given in Equation 2.3 was then applied to the values in each row of Tables 5-5 and 5-6 to produce values AWL_i and UWL_i. Table 5-7 shows these values, together with the values of the UWL_i-AWL_i difference, and the $P_i(UWL_i-AWL_i)$ and $P_i(UWL_i)$ products. These values were substituted into Equation 2.2 to produce $\Delta\overline{WL}$ -- the expected levels of workload reduction resulting from the Attack Planning decision aid. For this scenario tree, this expected reduction in operator workload is 58.89%, indicating a sizable decrease in operator workload resulting from this decision aid. There are three principal sources of this reduction. The first is the partial or complete automation of several tasks which in the unaided condition have high

Table 5-5. Unaided TACCO Workload in Attack Planning

SCENARIO	WORKLOAD MEASURE												
	COGNITIVE					PSYCHO-MOTOR		MOTOR		INTERACTIONAL			
	PLD	PRD	CLC	IPC	IAC	TBM	WTG	BPF	KEF	IFQ	IMG	CFQ	CMC
1	19	40	203	341	372	14	1	231	432	36	39	2	2
2	19	40	203	353	383	14	4	246	446	36	39	2	2
3	23	45	225	373	382	13	1	216	418	36	39	2	2
4	23	45	225	385	393	13	4	231	432	36	39	2	2
5	27	48	231	342	393	17	1	228	441	36	39	2	2
6	27	48	231	353	404	17	4	243	455	36	39	2	2
7	32	54	239	382	391	14	1	226	436	36	39	2	2
8	32	54	239	394	402	14	4	241	450	36	39	2	2

Table 5-6. Aided TACCO Workload in Attack Planning

SCENARIO (i)	WORKLOAD MEASURE												
	COGNITIVE					PSYCHO-MOTOR		MOTOR		INTERACTIONAL			
	PLD	PRD	CLC	IPC	IAC	TBM	WTG	BPF	KEF	IFQ	IMG	CFQ	CMC
1	15	39	141	326	391	6	1	215	483	21	18	2	2
2	15	39	141	338	402	6	4	230	499	21	18	2	2
3	18	44	152	361	404	5	1	205	472	21	18	2	2
4	18	44	152	373	415	5	4	220	488	21	18	2	2
5	22	47	141	338	400	8	1	212	480	21	18	2	2
6	22	47	141	350	415	8	4	227	496	21	18	2	2
7	29	53	152	371	408	6	1	210	475	21	18	2	2
8	29	53	152	383	419	6	4	225	489	21	18	2	2

Table 5-7. Comparison of Aided and Unaided TACCO Workload in Attack Planning

	Scenario(i)							
	1	2	3	4	5	6	7	8
UWL_i	45.99	44.84	31.06	29.91	66.96	65.96	44.94	43.79
AWL_i	31.57	31.01	13.41	12.86	36.97	37.54	28.20	27.05
$UWL_i - AWL_i$	14.42	13.83	17.64	17.05	39.50	28.42	16.73	16.73
P_i	.036	.144	.024	.096	.084	.336	.056	.224
$P_i\ (UWL_i - AWL_i)$	.519	1.99	.423	1.64	2.48	9.55	.937	3.75
$P_i\ (UWL_i)$	1.65	6.46	.745	2.87	5.58	22.16	2.51	9.81

workload -- the determination of attack criteria, the establishment of target fixes, and the generation of acoustic sonobuoy patterns. To the extent that an aiding algorithm can be constructed which successfully performs parts of these tasks, a substantial reduction of TACCO workload will result. The second source of the reduction is the lessening of the workload demands on the operator for many frequently performed tasks. With the information that would be presented and displayed by the aid (e.g., possible target fixes, probability contours for submarine location), the levels of cognitive workload involved are less than those involved in the same tasks as performed without the aid. The third source of reduction is the lessening of interruptions. With the automation of functions such as determination of attack criteria, the need for the TACCO to interrupt other functions to evaluate his possible attainment of attack criteria is reduced, thus allowing a smoother flow of procedures in this mission phase.

6. MAN/COMPUTER INTERFACE FOR THE SONOBUOY PATTERN PLANNING DECISION AID

The benefit assessment of the Sonobuoy Pattern Planning Decision Aid presented in Section 4 showed that this decision aid substantially increases mission performance levels during the on-station search portion of the mission without substantially affecting the (currently low) operator workload levels during this mission phase. Thus, further development of this aid is clearly warranted. The appropriate next steps in this development are to:

- define the man-computer interface for the Sonobuoy Pattern Planning Decision Aid, and
- build a working prototype of this interface.

There are two reasons why these steps should be undertaken next. The first concerns the aid's impact on operator workload. The workload assessment described in Section 4 was conducted with a purely analytic (i.e., non-experimental) methodology -- no actual measurement of TACCO workload was conducted, only the application of workload asessment scales. In order to confirm that this decision aid will not adversely impact operator workload, it is necessary to verify the analytical results by performing an experimental workload assessment using a prototype version of the Sonobuoy Pattern Planning decision aid. This experimental assessment requires the definition and development of a working prototype of the aid's man-computer interface.

The second reason concerns user-acceptance of the aid. The user-acceptance of a decision aid is largely a function of the aid's man-computer interface. Unfortunately, there are few *a priori* guidelines for the design of decision-aid interfaces, so it is necessary to take a more experimental approach to the interface design process. In this approach, the "useability" of the aid's interface is experimentally assessed by exposing potential users to the aid interface and measuring their experiences and attitudes involving its use. Those components of the interface which are found difficult and unpleasant to use are then changed; this procedure is repeated until a user-acceptable interface is constructed. A necessary prerequisite for this experimental assessment procedure is the development of one (or more) working prototype versions of the aid interface for use in the experiments.

As an intitial step in the development of the man-computer interface for the Sonobuoy Pattern Planning Decision Aid, this section presents an outline of a sample interface for this aid. Subsection 6.1 reviews the constraints that apply to the interface design for any decision aid to be implemented on an air ASW platform. Subsection 6.2 then discusses the input requirements of the Sonobuoy Pattern Planning Aid itself, and Subsection 6.3 presents the actual sample interface for this decision aid.

6.1 THE P-3C TACCO STATION ENVIRONMENT

Any decision aid implemented in an Air ASW platform must conform to a number of constraints imposed by the platform itself. These constraints will obviously vary from platform to platform according to the *specific* hardware and software operational on the aircraft. To keep the discussion manageable, this subsection concerns the specific constraints imposed by only one ASW aircraft, the P-3C Update.

A decision aid for the P-3C TACCO has to utilize in its interface only the basic input and output capabilities of the P-3C Update TACCO station. All decision aid output must be presented on the TACCO's Multipurpose Digital Display (MDD) or Auxiliary Readout (ARO). The general organization of the P-3C Update TACCO-station MDD is shown in Figure 6-1. The round display screen is divided into five areas: a central "tactical" square plus upper, lower, left, and right crescents surrounding this square. The tactical square is used

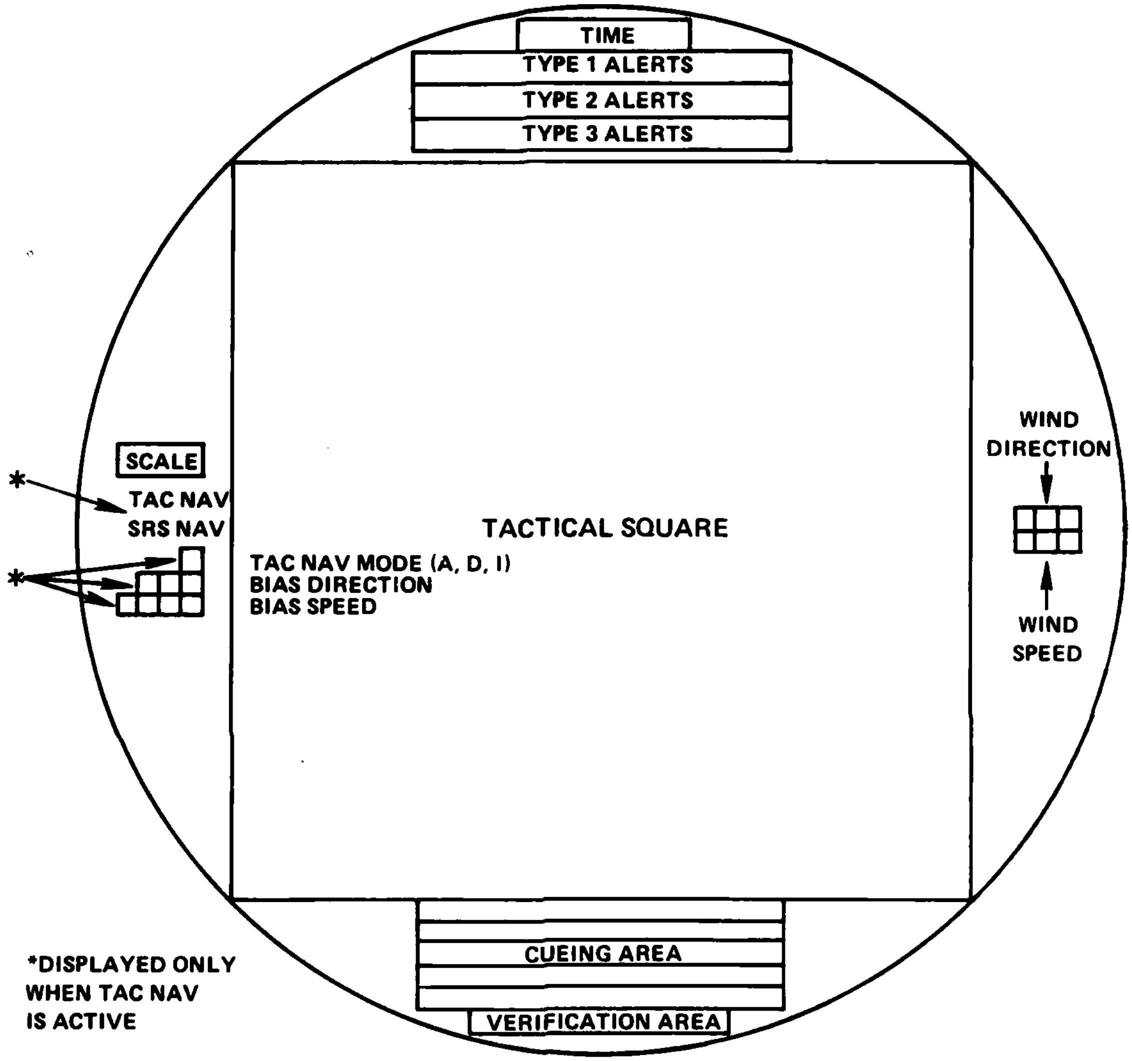

Figure 6-1. Organization of P-3C TACCO Multipurpose Digital Display (MDD)

for presentation of graphic outputs. The upper crescent is used only to display the time and various alerts. The right crescent is used only to display current wind data. The left crescent is used only to display the tactical navigation data and the scale factors used on the tactical square. The lower crescent is used for cueing and menu information, and for verification of data entered via the keyset. Additional details on the use of the MDD can be found in Reference 6. The central tactical square on the MDD can support monochromatic graphics, and utilizes standardized Navy symbology.

All software programs on the I4.4 operating system currently used on the P-3C Update aircraft employ a menu-driven format for selecting and entering data. Menus are displayed in the cueing area (lower crescent), and selections from the menu are made by depressing decision switches (Group C, M-35 through M-38) or via TACCO keyboard switches.

Multi-level menu structures are conventionally used in situations where there are multiple types of information that may be entered or requested; higher-level (i.e., initial) menus are used to select the kind of entry/request involved, and lower-level (i.e., subsequent) menus are then used to drive the actual input of data or presentation of output.

All input must be entered through the existing keyset, trackball, and function keys available at the TACCO station. Graphic input in the tactical square is possible via the trackball unit and associated function keys (e.g., HOOK-VERIFY). Alphanumeric input is accomplished via the keyset unit associated with the TACCO station.

All decision aids implemented in the P-3C Update aircraft must observe these constraints and conventions. They have to employ standard Navy symbology, and utilize menu-driven formats for data selection and input. They have to present their menus in the cueing area of the MDD, and restrict the menu lengths to the number of lines available in the menu-display crescent.They may utilize only monochromatic displays and only the graphic input capabilities of the trackball and associated function keys. In addition, all software interfaces must be compatible with the I4.4 operating system. These are the considerations that were taken into acount in designing the interfaces for the Sonobuoy Pattern Planning Decision Aid and presented below in Subsection 6.3

6.2 GENERAL SONOBUOY PATTERN PLANNING AID INPUT REQUIREMENTS

Before the details of the man-computer interface for the sonobuoy Pattern Planning Decision Aid can be presented, it is necessary to review the general kinds of inputs the aid requires in order to select and/or recommend a sonobuoy pattern.

The decision aid algorithm requires target and oceanographic information, the Submarine Probability Area (SPA), and sensor information to generate a target Figure-of-Merit (FOM). It then uses this FOM to supply to the TACCO (subject to any constraints he may have placed on the pattern selection process), with sonobuoy geometries, spacings, orientations, types, and settings. There are thus three major types of input the TACCO must make to the aid. He must:

- input data necessary to calculate the FOM,
- input data on the SPA,
- input any constraints and/or preferences for the pattern selection process.

Each type of input is further discussed below.

6.2.1 Input of Data for FOM Calculation

Data on target and oceanographic conditions and on all possible targets-of-interest are required to define a target FOM which specifies the target's detection ranges. FOM calculation is accomplished with the passive omnidirectional sonar equation, given by:

$$SE = SL - PL - AN - RD$$

where SE is the signal excess,

SL is the level or magnitude of the signal at its source (i.e., the submarine),

PL is the amount of the signal lost due to acoustic propagation between the source and the "listeners,"

AN is the ambient noise percent in the propagation medium, and

RD is the recognition differential level of signal required by the listener to recognize the signal.

Assuming that zero signal excess is defined as that point at which the opertor has a 50 percent probability of detecting a signal, this equation can be expressed as:

$$SE = 0 = SL-PL-AN-RD$$

or, by simple algebra,

$$PL = SL-AN-RD$$

This equation defines the amount of acoustic propagation loss beneath which there is no signal excess. Since propagation loss is dependent on distance, the value defines the range at which a target can be heard. This is then the target's FOM, so

$$FOM = SL-AN-RD$$

Therefore, the target source levels, the ambient noise, and the recognition differential must be established to determine the FOM. The FOM is then combined with the propagation-loss-by-distance profile for the ocean area being searched to determine target detection ranges.

The *target source levels* are supplied to the aircrew at mission briefing and stored on the Preflight Data Insertion Program (PDIP) tape. These levels do not change drastically during the mission and cannot be accurately measured by the normal P-3C aircraft sensors and tactics anyway. The *recognition differential* for a specific acoustic processor is directly related to the specific mode in which the processor is operated. These values can be determined and stored (by processor mode) on the PDIP tape; this would require the TACCO only to inform the decision aid of the mode in which this processor is being operated.

The only remaining variables in the solution of the passive sonar equation are propagation loss and ambient noise. Currently, the aircrews are provided with predicted propagation loss or PL profiles and base all sonobuoy pattern selecting upon these predicted conditions even if they are not the conditions which obtain in the search area. Nonetheless, when the aircraft arrives on-station, the aircrew deploys a bathythermal (BT) recording sonobuoy, which provides them with data on the oceanographic bathythermal conditions from which PL can be computed. Thus, the decision aid requires the TACCO to enter the current BT data obtained from the BT sonobuoy to the decision aid so that it can compute the necessary PL profile itself.

This leaves only ambient noise unaccounted for in the passive sonar equation. When the aircrew arrives on-station, it deploys an ambient noise-recording sonobuoy along with the BT sonobuoy. The TACCO can enter the ambient noise data recorded by this sonobuoy into the decision aid along with the BT data, thus providing the last item of information needed to calculate the target FOM.

6.2.2 Input of Submarine Probability Area Data

The generation of sonobuoy pattern recommendations is dependent on the target FOM but also on the submarine probability area as well. The shape of the area in which the submarine is believed to be, and the probability density of the location of the submarine within this area, are crucial to the development of possible sonobuoy patterns. An initial SPA is supplied to the aid via the PDIP tape prior to take-off. However, it is important for the TACCO to be able to input to the decision aid any updated information on the SPA. Normally, SPAs have one of three shapes: ellipses, circles or rectangles. Occasionally, they may have some other polygonal shape. When the SPA is a circle or an ellipse it can be input to the decision aid by the coordinates of its center, and the lengths of its axes. When it is a rectangle it can be entered by the coordinates of two opposite vertices. And when it is some other polygon it can be entered by the coordinates of all its vertices.

6.2.3 Input of Constraints and TACCO Preferences

For a variety of reasons, the TACCO may wish to restrict the decision aid from considering certain possible alternatives. He may wish to (or may have been ordered to) eliminate certain pattern geometries from consideration, eliminate certain sensor settings from consideration, or eliminate certain sonobuoy settings from consideration. The decision aid must give the TACCO the option of entering restrictions of this sort to it.

6.3 SAMPLE INTERFACE FOR THE SONOBUOY PATTERN PLANNING DECISION AID

The Sonobuoy Pattern Planning aid is activated by depression of a switch marked SEARCH PATTERN, which causes the master or "main" menu to appear in the MDD cueing area. This menu controls the specification of the kind of input or output desired, and appears as:

```
INFO TO BE UPDATED
     D1   BT
     D2   AMBIENT NOISE
     D3   RD
     D4   MORE
```

Since there are only four cue-selection decision switches, only four elements of the menu can be displayed at any one time. Thus, the D4 MORE switch is required to display further portions of the menu.

If the D4 MORE decision switch is depressed, the "main" menu continues as:

```
INFO TO BE UPDATED
     D1  SPA
     D2  OP PREF
     D3  PATTERN SELECT
     D4  NONE
```

6.3.1 Menu and Cues for Entry of BT Data

If the TACCO depresses the D1 decision switch in response to the main menu to specify the entry of BT data, the following cue appears in the cueing area of the MDD:

ENTER SURFACE TEMP
xx.x

Where *xx.x* is a three digit number (with one explicit decimal place) entered by the TACCO from his keyset to indicate the water surface temperature measured by the BT sonobuoy. This cue is followed by:

ENTER LAYER DPTH/TEMP
xxx-x.x

Where *xxx* is a (three-digit) number entered by the TACCO specifying the depth of the thermal layer, and *xx.x* is three-digit number with one explicit decimal place entered by the TACCO, specifying the temperature associated with this layer. Both values are obtained from the BT sonobuoy. The next cues are:

ENTER DEPTH/TEMP EVERY
100 FT AND ANOMALIES
xxx-xx.x
xxx-xx.x
.
.
.
xxx-xx.x

Where *xxx* and *xx.x* are numbers entered by the TACCO representing the requested depth in feet and associated water temperatures as measured by the BT sonobuoy.

After the last depth/temperature pair has been entered, the TACCO depresses the function key indicating end-of-entry, and the main menu returns to the cueing area. At this point, the TACCO can choose to enter more information, update information already entered, request the aid's output, or exit the aid.

6.3.2 Menu and Cues to Input Ambient Noise Data

If the TACCO depresses the D2 decision switch after the main menu appears to specify AMBIENT NOISE, the following cues appear in the cueing area of the MDD:

ENTER AMBIENT NOISE
hz-xxx
hz-xxx
.
.
hz xxx

Where *hz* and *xxx* are pairs of numbers entered by the TACCO. Each *hz* is a number indicating a frequency (in hertz) at which ambient noise was measured by the ambient noise sonobuoy, and *xxx* is a three digit number indicating the ambient noise level measured at that frequency. After all frequencies and noise levels are entered, the TACCO depresses the end-of-entry key and the main menu reappears.

6.3.3 Menu and Cues to Input Recognition Differential Data

If the TACCO depresses decision switch D3 after the main menu to specify RECOGNITION DIFFERENTIAL, the following menu appears in the cueing area:

ENTER PROCESSOR MODE
D1 *aaa*
D2 *bbb*
D3 *ccc*
D4 MORE

Where *aaa, bbb*, and *ccc* are the names of specific processing modes for the acoustic processor used on-board that aircraft. If one of the three modes displayed is the one being used, the TACCO depresses the decision switch which corresponds to that mode. Otherwise, he depresses switch D4, and another menu listing more processor modes is displayed. This process continues until a mode-selection is indicated. After that decision key is depressed, the main menu then reappears in the MDD.

6.3.4 Menu And Cues To Enter/Update The SPA

If from the initial portion of the main menu the TACCO depresses decision switch D4 to indicate MORE, the following secondary portion of the main menu appears:

INFO TO BE UPDATED
D1 SPA
D2 OP PREF
D3 PATTERN SELECT
D4 NONE

If the TACCO depresses the D1 decision switch at this point to specify SPA the following menu appears in the cueing area:

DEFINE SPA SHAPE
D1 ELLIPSE
D2 CIRCLE
D3 RECTANGLE
D4 OTHER

Depending on the SPA shape indicated by the TACCO, four possible sequences of cues may follow from this point. Since they are largely similar, only one set of these is presented here, those used to enter a SPA with an elliptical shape.

If from the DEFINE SPA SHAPE menu the TACCO depresses the D1 decision switch to specify an elliptical SPA, the following cues appear in the cueing area of the MDD:

LOCATION
xx xx xx i (latitude)
xxx xx xx i (longitude)

where the two lines following the location cue are (respectively) a latitude and longitude entered by the TACCO to indicate the center of the SPA. Each value is entered in degrees, minutes, and seconds along with an indicator to specify it as either east/west or north/south. After this center coordinate has been entered, this cue appears in the cueing area:

SEMIMAJOR
xxx

Where *xxx* is the length of the semi-major axis of the ellipse entered by the TACCO. Then, the following cue appears:

SEMIMINOR
xxx

Where *xxx* is a number entered by the TACCO to indicate the length in nautical miles of the semi-minor axis of the ellipse. The final cue in this sequence then appaears:

ORIENTATION
xxx

Where *xxx* is the orientation of the ellipse (degrees of displacement from true north) provided by the TACCO. At this point the SPA is completely defined, and the main menu reappears.

6.3.5 Menu and Cues to Input Operator Preferences and Constraints

When the TACCO depresses the D2 decision switch after the second portion of the main menu to indicate OP PREF (for operator preferences), the following menu appears in the cueing area:

TACCO PREFERENCE
D1 PATTERN
D2 BUOY TYPE
D3 BUOY SETTING
D4 NONE

The depression of decision switch D1 at this point indicates a desire to set constraints on the pattern geometries considered in the sonobuoy pattern planning process, and results in the following tertiary menu being displayed:

PATTERN PREFERENCE
D1 1 PATTERN
D2 2 PATTERNS
D3 3 PATTERNS
D4 MORE

Through this menu (and its continuation) the TACCO selects the number of patterns he wishes to include in the pattern-selection process. The continuation frames of this menu simply allow the selection of a higher number of patterns. The exact number of patterns allowable is dependent on the number of geometries stored in the decision aiding algorithm's data base, which in turn is dependent on current tactical procedures. Once the number of desired patterns is selected, another tertiary menu appears in the cueing area, as follows:

PATTERN TYPE
D1 *aaa*
D2 *bbb*
D3 *ccc*
D4 MORE

Where *aaa*, *bbb*, and *ccc* are names of pattern geometries. This menu, which is continued over as many segments as needed to list all geometries included in the aid's data base, allows the TACCO to select explicitly the pattern geometries desired for inclusion in the decision aid's calculations. While each portion of the pattern type menu is displayed, the TACCO can depress the decision switches D1 through D3, to select the corresponding patterns for inclusion in the pattern selection process, or he can depress switch D4 to see further portions of the menu. When as many patterns as indicated in the previous menu have been selected, the secondary (TACCO PREFERENCE MENU) reappears in the cueing area:

TACCO PREFERENCE
D1 PATTERN
D2 BUOY TYPE
D3 BUOY SETTING
D4 NONE

The depression of the D2 decision switch to specify BUOY TYPE results in the presentation of the following tertiary menu in the cueing area of the MDD:

BUOY TYPE
D1 *aaa*
D2 *bbb*
D3 *ccc*
D4 MORE

Where *aaa,bbb* and *ccc* are names of sonobuoy types. To select the specific type desired for use in the pattern being planned, the TACCO selects the decision switch that represents it in this or subsequent portions of this menu. Once a sonobuoy type for the pattern has been selected, the secondary TACCO PREFERENCE menu reappears.

The depression of the D3 decision switch to specify BUOY SETTINGS from the TACCO PREFERENCE menu results in the presentation of the following tertiary menu on the cueing area of the MDD:

BUOY SETTING
D1 SHORT/SHALLOW
D2 SHORT/DEEP
D3 LONG/SHALLOW
D4 LONG/DEEP

The TACCO then depresses the decision switch which corresponds to the buoy life and depth settings desired for the pattern being constructed. After this, the aid returns to the TACCO PREFERENCE menu.

When the D4 decision switch is depressed for the TACCO PREFERENCE menu, to indicate NONE, the aid returns to the main menu.

6.3.6 Menus and Cues to a Sonobuoy Pattern: Decision Aid Output

Once all the necessary input information has been entered and/or updated, the TACCO may depress the D3 decision switch from the second portion of the main menu to request the decision aid's output and from it select a sonobuoy pattern. When this switch is depressed, a tableau is automatically presented showing the oceanographic information upon which the aid's pattern selection calculations are based. This tableau is displayed in the auxiliary readout (ARO) adjacent to the TACCO's MDD. This Oceanographic Tableau would appear as shown in Figure 6-2; the numbers shown there are hypothetical and are included merely to indicate how the complete tableau would look.

OCEANOGRAPHIC	
DIRECT PATH	237nm
CZ1R	16nm
CZ1W	04nm
CZ2R	39nm
CZ2W	12nm
CZ3R	*nm
CZ3W	*nm
FOM VALUE	73
BUOY TYPE	SSQ99
BUOY DEPTH	S
FREQUENCY	2391.25
AMBIENT	79
RD	12
PROC MODE	F1.VERN

ARO DISPLAY

This tableau provides information on the target detection ranges in lines one through seven by specifying the direct path radius and the radii and widths of up to three convergence zones. If a given convergence zone does not exist, the values are replaced by asterisks, as in lines six and seven in this example. The next line (eight) lists the target FOM (in db). The next two lines (nine and ten) indicate the optimal sonobuoy type and depth setting for these acoustical propagation conditions. The frequency for the indicated detection ranges is displayed in line eleven, and the ambient noise level and recognition differential at this frequency are displayd in lines twelve and thirteen respectively. The last line in the display indicates the acoustical processing mode (as input by the TACCO) for which the above data apply.

Figure 6-2. Oceanographic Tableau for Sonobuoy Pattern Planning Decision Aid

Simultaneous to the display of this tableau, the following menu appears in the cueing area of the MDD:

PATTERN SELECT
- D1 ACCEPT AID PATTERN
- D2 PATTERN TABLEAU
- D3 OCEANOGRAPHIC TABLEAU
- D4 SELECT PATTERN

If the TACCO wishes to deploy whatever pattern the aid determined to be optimal without reviewing any data on other near-optimal patterns, he depresses the D1 decision switch. This causes that pattern (i.e., the one selected by the aid) to be displayed in the Tactical Square area of the MDD, along with the current SPA and the fly-to-points necessary to deploy the pattern. Any data already on the MDD (e.g., the locations of the BT and AN sonobuoys) is retained on the screen when this new information is added.

In many if not most circumstances, however, the TACCO will want to examine some of the alternative near-optimal patterns before selecting a pattern for deployment. The TACCO might have external reasons for selecting a pattern other than the one chosen by the aid; to do so he must have access to a set of alternative or candidate patterns. To view additional patterns, the TACCO depresses the D2 decision switch from the PATTERN SELECT menu. This causes the Oceanographic tableau to disappear from the ARO and be replaced by a tableau summarizing all sonobuoy patterns found by the decision aid to be optimal or near-optimal. This tableau, called the Pattern Tableau, would appear as shown in Figure 6-3. It indicates the pattern geometry, orientation, and spacing of each pattern (to completely specify it to the TACCO), along with several criteria by which the patterns' effectivenesses may be compared. The specific criteria presented in this tableau depend on the ultimate algorithm employed by this decision aid, but for demonstration purposes four are shown in Figure 6-3. These are:

- coverage area,

PATTERN	
P1 GEOM	CROSS
P1 SPCG	239nm
P1 PDTR	.77
P1 PDHLD	.97
P1 CVG	87%
P1 DPLYTM	127m
P2 GEOM	LINE
P2 SPCG	69nm
P2 PDTR	.72
P2 PDHLD	.46
P2 CVG	64%
P2 DPLYTM	49m
P3 GEOM	CROSS
P3 SPCG	166nm
P3 PDTR	.77
P3 POHLD	.72°
P3 CVG	.72%
P3 DPLYTM	234m

ARO DISPLAY

This tableau presents data on the optimal and suboptimal patterns as determined by the aid. In the initial portion of this tableau, lines one through six specify the characteristics of the pattern determined by the aid to be optimal -- its geometry, its spacing, its probability of detecting a transiting target, its probability of detecting a holding target, its percentage coverage of the SPA, and its time for deployment (in minutes). The next six lines present the same data for the pattern the aid found to be second best, and the next six lines present the same data for the pattern found to be third best. In each case the number following the initial P (for Pattern) indicates the order in which that pattern appeared in the aid's calculations. If the TACCO depresses the decision switch indicating this tableau on the menu when it is already displayed, a subsequent portion of it will appear in the ARO, specifying the next three patterns (in order of quality). This can be continued as long as the TACCO desires to see more patterns.

Figure 6-3. Pattern Tableau for Sonobuoy Pattern Planning Decision Aid

- transiting target probability of detection (Pd) during the lifespan of pattern,
- holding target Pd during the lifespan of pattern, and
- time required to deploy entire pattern.

The coverage area is simply the percentage of the ocean area within the SPA that is covered by that pattern. The transiting target Pd is the probability of detecting a target transiting through the SPA during the active life of the sonobuoys in that pattern. The holding target Pd is identical, except it concerns a target maintaining a holding pattern within the SPA. The time required to deploy the pattern is self-explanatory.

By presenting the TACCO with these data, the aid allows the TACCO to assess its choice, and possibly select a different pattern based on external criteria or on a different weighing of the criteria shown in the tableau.

After the pattern tableau is displayed, the PATTERN SELECT menu reappears in the cueing area of the MDD. At this point, the TACCO may decide to redisplay the Oceanographic Tableau in the ARO, which he can do by depressing the D3 decision switch. This causes the Pattern Tableau to be replaced in the ARO by the Oceanographic Tableau. The PATTERN SELECT menu then reappears in the MDD cueing area.

If the TACCO has viewed the Pattern Tableau and decides to select the pattern originally recommended by the decision aid, he can indicate this by depressing decision switch D1. This results in the actions described above. However, if the TACCO decides to deploy upon another pattern shown in the Pattern Tableau (or another pattern altogether), he depresses decision switch D4. This causes the following menu to appear in the MDD cueing area:

CHOOSE PATTERN
D1 *zzz*
D2 *yyy*
D3 *xxx*
D4 MORE

Where *zzz*, *yyy*, and *xxx* are patterns shown in the Pattern Tableau. If the TACCO wishes to deploy one of these patterns, he depresses the associated decision switch. That pattern then appears in the tactical square area of the MDD along with the SPA, and whatever information was already there. The output is analogous to that presented if decision switch D1 is depressed from the PATTERN SELECT menu.

If there were more than three patterns displayed on the Pattern Tableau and the TACCO wished to select one of them not indicated in the initial portion of the CHOOSE PATTERN menu, he depresses the D4 switch to view the remainder of this menu:

CHOOSE PATTERN:
D1 *aaa*
D2 *bbb*
D3 *ccc*
D4 OTHER

Where, as before, *aaa*, *bbb*, and *ccc* are patterns from the Pattern Tableau. If the TACCO wants to select one of these, he simply depresses the associated decision switch.

If, however, the TACCO wishes to deploy a pattern not shown in the Pattern Tableau, he depresses the D4 switch after the presentation of this second portion of the CHOOSE PATTERN menu. This causes the following menu to appear in the cueing area of the MDD:

SELECT GEOMETRY:
D1 *aaa*
D2 *bbb*
D3 *ccc*
D4 MORE

Where *aaa*,*bbb*, and *ccc* are pattern geometries from the aid's data base of pattern geometries. The TACCO depresses the decision switch which corresponds to his choice of pattern geometry, or the D4 switch to view further patterns. After a pattern geometry has been chosen, this cue then appears:

ENTER ORIENTATION
xxx.x

where *xxx.x* is a number entered by the TACCO to specify the orientation of the pattern. After this has been entered, the following cue appears:

ENTER SPACING:
xx.xx

where *xx.xx* is a number entered by the TACCO to indicate the spacing (in nautical miles) between buoys in the pattern. This cue may be presented in two parts for patterns which have two spacing parameters (e.g., within rows and between rows). The selection of a geometry, orientation, and spacing completely define the pattern to be deployed. After the spacing has been entered, the aid then displays the selected pattern on the MDD, along with the other relevant information (fly-to-points) plus whatever information was already on the MDD.

Regardless of how the final pattern is selected (by the aid, by the TACCO from the Pattern Tableau, or by the TACCO on his own), once the pattern choice is indicated to the aid and displayed on the MDD, the sonobuoy Pattern Planning Decision aid terminates execution. The aid can also be terminated at any time by depressing the D4 decision switch in response to the second portion of the main menu.

7. CONCLUSIONS AND RECOMMENDATIONS

The research reported here has produced a number of significant results from both applications and methodological perspectives. It has generated a methodology for assessing the:

- direct benefits of a decision aid as expressed by increase in mission achievement,
- indirect benefits of a decision aid, as expressed by reduction of operator workload,
- research and development costs of a decision aid,
- acquisition and implementation costs of a decision aid, and
- operation and maintenance costs of a decision aid.

This effort has also continued the progress in a program to develop decision aids for Naval Air ASW. In particular, it has:

- assessed the direct and indirect benefits of a decision for Sonobuoy Pattern Planning,
- assessed the direct and indirect benefits of a decision aid for Attack Planning, and
- developed a detailed specification for the man-computer interface for the Sonobuoy Pattern Planning decision aid.

The benefit assessment methodology developed here (Figure 2-1) provides an analytic approach to a hitherto unexplored issued in decision-aiding research -- the "aidability" of a decision-making situation by a candidate decision aid for it. Although the determination that the decision situation is important to the tactical arena involved (i.e., has high priority for decision aiding) is one necessary condition for aid development, another is that the decision-making performance in that situation be amenable to some sort direct or indirect improvement via decision aiding. If the situation is not aidable in this manner, then the construction of a decision aid for this situation is not warranted.

The benefit assessment methodology outlined in Section 2 not only allows detailed assessments of the likely increases in mission achievement and decreases in operator workload to be expected from a candidate decision aid, it also allows this assessment to proceed from high-level designs of the sort which characterize the earliest phases of the aiding system's life cycle. Thus, this methodology allows the important question of the decision-situation aidability to be answered as early as possible in the process of decision-aid development.

The cost assessment methodology developed here (Figure 3-1) provides a mechanism to anchor or judge a decision aid's estimated benefits. The cost assessment procedure outlined in Section 3 allows the actual life cycle costs of a decision aid to be estimated at the same early stage at which the benefit methodology allows its benefits to be estimated. This makes it possible to relate the level of performance improvement expected from the aid to its unit-level cost. With this cost/benefit data, the system designer and the policy maker can make the necessary tradeoffs between investment costs and need for increased achievement.

The application of the benefit assessment methodology to the designs for the Sonobuoy Pattern Planning decision aid (Section 4) and the Attack Planning decision aid (Section 5) has resulted in quantitative indications of the increases in mission achievement and decreases in operator workload that are possible with candidate decision aids for the Air ASW decision situations involved -- On-Station Search and Attack Planning. It has shown that the Sonobuoy Pattern Planning aid affects operator workload levels relatively little, for two reasons. First, it concerns a portion of the Air ASW mission in which workload is already relatively low. Second, the aid automates some TACCO tasks but gives him the power to make certain decisions (such as the choice of an initial sonobuoy pattern) which he currently cannot. Thus, it both adds to and diminishes workload (although in different ways), with a net result of little change. From the perspective of mission achievement, however, the picture is quite different. Within the scenario of initial search pattern selection, the Sonobuoy Pattern Planning decision is shown to possess potential for an almost twofold improvement in performance -- one of 87.1 percent. This clearly demonstrates that by placing the choice of an initial search pattern in the hands of the TACCO as assisted by the decision aid, the effectiveness of on-station search can be dramatically improved.

The benefit assessment of the Attack Planning decision aid also produced striking results. It shows that this aid can produce substantial increases in mission achievement, both by increasing the probability-of-kill once attack criteria have been gained on the submarine, and by shortening the length of time required to gain attack criteria. The benefit assessment of this aid has also shown that a substantial reduction of operator workload is possible with the introduction of the aid. The interviews with fleet personnel as well as the psychometric data reported in Zachary (1980b) indicated that the Attack Planning mission phase gives the TACCO his heaviest workload, and the analysis and formalization of TACCO Attack Planning procedures conducted during the benefit assessment of this aid bore this out. More importantly, however, this analysis also showed that in this workload-intensive period, the Attack Planning decision aid can bring about a definite reduction of the TACCO's workload.

The benefit analyses of these two decision aids clearly justify their continued development. The next logical step in this development process is the construction of the actual aiding algorithm and man-computer interfaces for these aids. To this end, Section 6 presented a detailed specification for one possible man-computer interface for the Sonobuoy Pattern Planning decision aid. Because the user-acceptability of a decision is such an important consideration, it is recommended that continued research be devoted to conducting experiments with this and other candidate interfaces to determine the combination of features which will lead to the maximum acceptance of the aid by its target user population. It is further recommended that the detailed specifications for the aiding algorithm necessary to drive this interface should be constructed, but only after the man-computer interface has been thoroughly tested, refined, and its design finalized. By proceeding in this fashion, an optimal realization of this decision aid can ultimately be achieved.

APPENDIX A

SCENARIO TREE FOR SONOBUOY PATTERN PLANNING

A. SCENARIO TREE FOR SONOBUOY PATTERN PLANNING

This appendix presents the scenario used in assessing the design of the Sonobuoy Pattern Planning Decision Aid. Some of the information contained here is also used in the scenario for the assessment of the Attack Planning Decision Aid presented in Appendix B. Section A.1 outlines the general, underlying features of the scenario -- the "trunk" of the scenario tree. Section A.2 describes the branch contingencies which give rise to different scenario evolutions, and Section A.3 presents the mechanism employed to combine the various contingencies into the scenario tree used in Section 4 above to assess the Sonobuoy Pattern Planning Decision Aid.

A.1 BASIC SCENARIO -- PREFLIGHT INFORMATION

The Sonobuoy Pattern Planning Decision Aid resides on-board the ASW aircraft and function after the aircraft has taken off. As described in Section A.2, information may be passed to the platform while enroute to its search area, so different evolutions of the mission scenario may begin as early as takeoff. The basic information provided to the aircrew during its preflight brief, however, is common to all variants of this mission, and is therefore the "core" of the scenario. This preflight data is the information is given in this section, although some information normally contained in the preflight packet is intentionally deleted to avoid the use of classified information. The deleted information does not affect the usefulness of the scenario for decision-aid assessment.

In this scenario, the Anti-Submarine Warfare Operational Control (ASWOC) has received notification from a SOSUS station that an enemy submarine has been detected and appears to be in an intercept course with a friendly convoy. The initial submarine probability area (SPA) is centered approximately 1000 nm from the land base. The SPA is an elliptical area with semi-major and semi-minor axis of 100 nm and 75 nm respectively. The ASWOC officer determines that this submarine should be prosecuted and destroyed if it poses a threat to the convoy. Preparation for launch of an ASW aircraft should therefore commence.

The aircrew is alerted to a 1630 (all times local) briefing for a 2000 takeoff. The on-station period commences at 2330 and is completed by 0400, with a landing at 0730. The ASWOC officer reviews all target intelligence information and tactical manuals to determine the desired initial sonobuoy search pattern, orientation, and sonobuoy locations to be employed.

Table A-1 summarizes the characteristics of the aircraft flown in the ASW mission. Table A-2 summarizes the expected environmental conditions in the search area. The predicted acoustic propagation loss profile on which the environmental prediction is based is shown in Figure A-1. The flight profile for the mission is given in Table A-3, and a summary of friendly, enemy, and other forces in the search and transit area is given in Table A-4. The initial submarine probability area data and recommended initial search pattern is given in Table A-5. It is initially recommended that the signal processing equipment be operated in normal full mode. The information on the search area and search pattern has been randomly altered to render it unclassified.

Table A-1. Aircraft Information

<u>AIRCRAFT INFORMATION</u>	
Aircraft Type:	P-3C Update II
Sensors Available:	AQA-7v1 (single vernier)
	Radar (primarily surface plots)
	ESM (primarily surface/threat warning)
	IRDS
	MADS
Sonobuoy Utilization:	SSQ36 -- Bathythermal checking
	SSQ57 -- Ambient noise
	SSQ41B -- LOFAR search/track
	SSQ53 -- DIFAR investigate/track
	SSQ50 -- Active preattack fixing
	SSQ47 -- Active preattack fixing
Attack Criteria:	As specified in P-3 Tactical Reference Manual
Weapon Inventory:	4 MK-46 torpedoes

Table A-2. Environmental Data

ENVIRONMENTAL DATA

Predicted Environment: (based upon target and assumes in layer setting)	Direct path range = 2.5 nm
	Convergence Zone #1 radius = 27 nm
	Convergence Zone #1 width = 3 nm
	Convergence Zone #2 radius = 57 nm
	Convergence Zone #2 width = 3 nm
	SSQ-50 active range = 3500 yds.
	SSQ-47 active range = 2800 yds.
On-Station Weather:	Night time: 1st quarter moon
	Cloud cover: scattered at 4500 ft.
	Winds at 20,000 ft.: 340°T/45 kts.
	Winds at 5,000 ft.: 295°T/23 kts.
	Winds at sea level: 180°T/12-15 kts.
	Precipitation: none
	Sea state: 3
	Wave height: 2-4 ft.

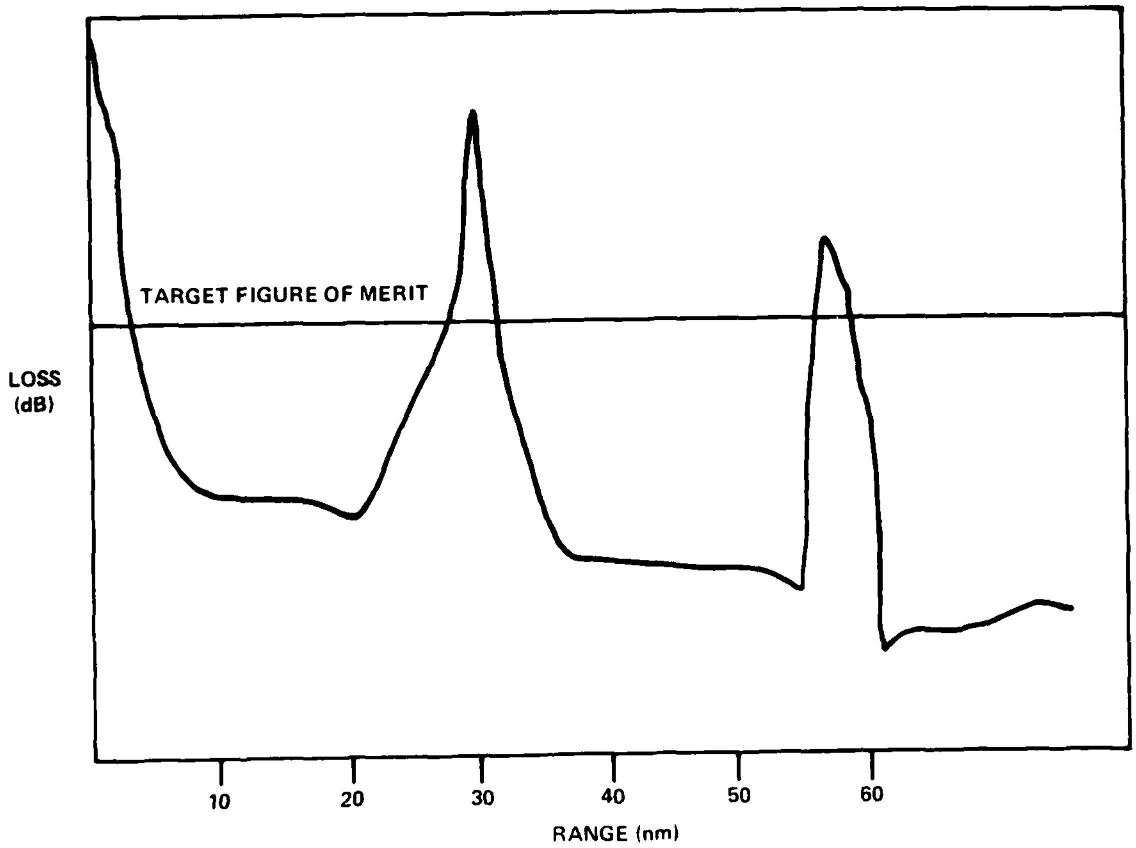

Figure A-1. Predicted Environment

Table A-3. Flight Data

Flight Profile:	7 hrs. enroute (3-1/2 hrs. one way) 4.5 hrs. on-station crew brief/preflight 3-1/2 hrs. prior to T/O
Time Schedule: (all times local)	SPA obtained 1400 Brief/Preflight 1630 Takeoff 2000 On-Station 2330 Off-Station 0400 Land/Debrief 0730

Table A-4. Forces in Area

FORCES IN AREA

Friendly Forces:	SOSUS station (via ASWOC/CV-ASWM) for probability area/intelligence updates. ASWOC/CV-ASM for intelligence and aircraft control. Convoy for emergency and miscellaneous data. Relief aircraft if needed at the end of scheduled on-station.
Enemy Forces:	Target submarine.
Other Forces:	Light to moderate shipping density in shipping lanes approximately 30 nm North of SPA. Potential of fishing vessels in operating area.

Table A-5. Target Probability Area

PREDICTED SUBMARINE PROBABILITY AREA AT ON-STATION TIME

1400 Elliptical: semi-major axis 100 nm
semi-minor axis 75 nm
orientation 085° T
Recommended pattern: 4x4 sawtooth 23 nm spacing

Most relevant data on the target submarine's tactics and mission are not known to the ASWOC or ASW aircrew. There is only a single hostile submarine in the scenario, with mission and tactics as follows. The submarine:

- is initially unalerted to ASW aircraft presence,
- is performing ESM plots when possible,
- can detect active sonobuoys at approximately 1.5 times active sonobuoy detection range,
- will go evasive whenever it determines that aircraft's presence is a threat to its mission,
- is transiting to on-station with a speed of advance (SOA) of 6 kts.,
- has heading uncertainty along PIM + or - 15°.

The submarine is transiting to intercept a convoy. Its course is to be maintained relatively constant between navigation points with small excursions for baffle clearings.

The aircrew completes the preflight check of the aircraft and prepares to take off at the assigned time. Once airborne and enroute to the operating area, an inflight check of the aircraft system reveals no discrepancies. The only task which must be performed by the tactical crew during the enroute phase is navigation and monitoring of the communications systems for updated target intelligence information.

The scheduled functions to be accomplished upon arrival on-station are as follows:

- Deploy a bathythermal sonobuoy (SSQ-36).
- Deploy an ambient noise measuring sonobuoy (SSQ-57).
- Deploy the sonobuoy pattern (SSQ-41).

The purpose of the SSQ-36 and SSQ-57 sonobuoys is to obtain actual oceanographic environmental information. If the Tactical Coordinator (TACCO) has the capability to modify the briefed sonobuoy pattern based upon updated condition, a new pattern can be created and deployed. Unless otherwise specified in a contingency below, it is be assumed that he does not have this capabilty.

Once the search sonobuoy pattern is deployed, the aircrew monitors the sonobuoy signals for target information. Monitoring continues until either the sonobuoys are no longer useful, the on-station period has terminated, or contact is gained. Once contact is gained, the TACCO directs the aircrew in the prosecution, localization and attack of the target.

A.2 SCENARIO VARIATIONS

There are a large number of factors in this general scenario framework which could be varied to produce the required broad spectrum of mission conditions, but only two are directly relevant to the candidate decision aid being assessed here. These are the in-situ environmental conditions and the Submarine Probability Area (SPA).

In the following subsections, four contingencies in the scenario are described. In two of these, the ASW aircraft encounters different in-situ environmental conditions than those predicted (see Table A-2 and Figure A-1). In two others, the target SPA is updated (in different ways and at different points in time) from that indicated in Table A-5.

A.2.1 Contingency I: Environmental Variation A

As the aircraft arrives on-station, the bathythermal and ambient noise sonobuoys are deployed. Analysis of the data from these sonobuoys reveals that the predicted oceanographic environmental information is not consistent with the actual conditions. If the TACCO were capable of determining the oceanographic environmental conditions, he would find the propagation loss profile shown in Figure A-2, rather than the predicted shown in Figure A-1. In this case, the actual CZ1R would be 32 nm, the CZ1W would be 4 nm, and there would be a potential CZ2R at 64 nm, with a CZ2W of 3 nm. The actual occurrence of a CZ2 would be dependent upon the actual source level of the target and the stability of the ambient noise. If the brief data are correct, the CZ2 is available. However, if the briefed source level is 2 db high, or the ambient noise is 2 db low, no CZ2 is available.

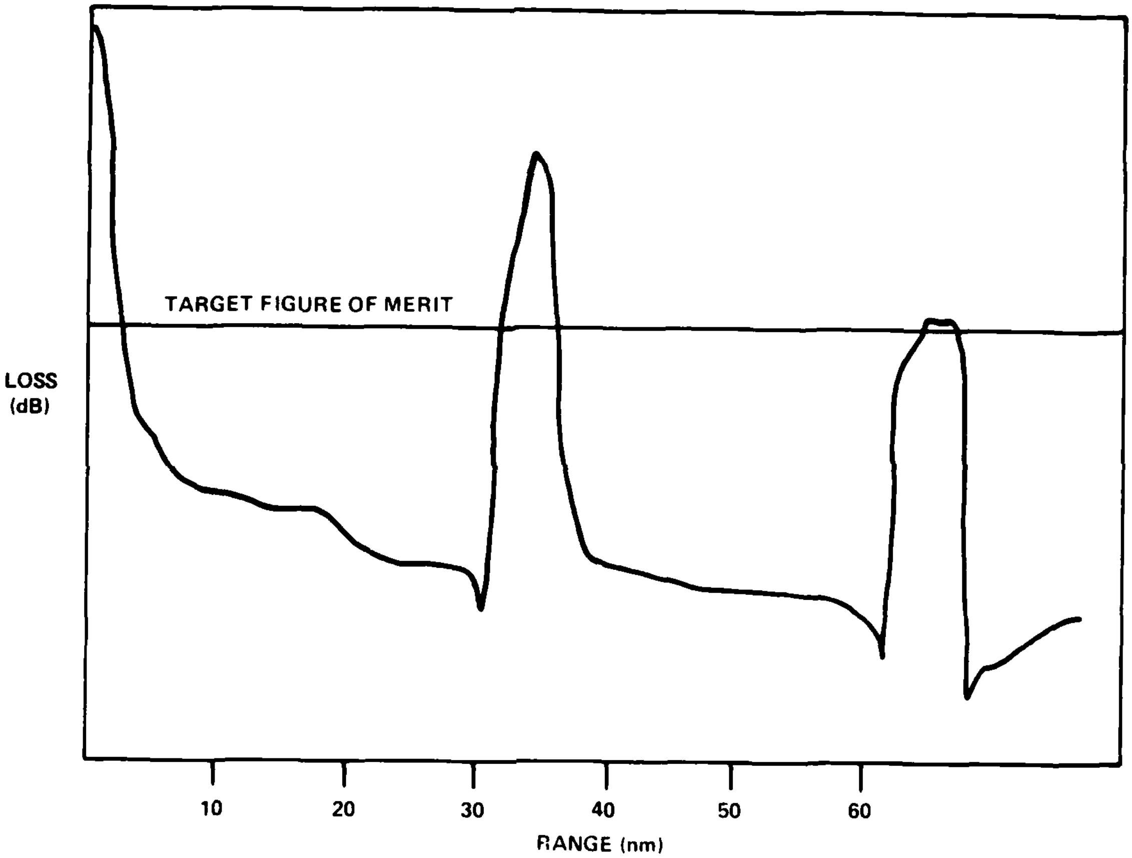

Figure A-2. Environment (Variation A)

A.2.2 Contingency II: Environmental Variation B

As the aircraft arrives on-station, th bathythermal and ambient noise sonobuoys are deployed. The results of these sonobuoys reveals that the predicted oceanographic environmental information is not consistent with the actual conditions. If the TACCO were capable of determining the oceanographic environmental conditions, he would find the propagation loss profile shown in Figure A-3, rather than the one shown in Figure A-1. In this case, the actual CZ1R would be 32 nm and the CZ1W would be 4 nm. There would be no potential of a CZ2.

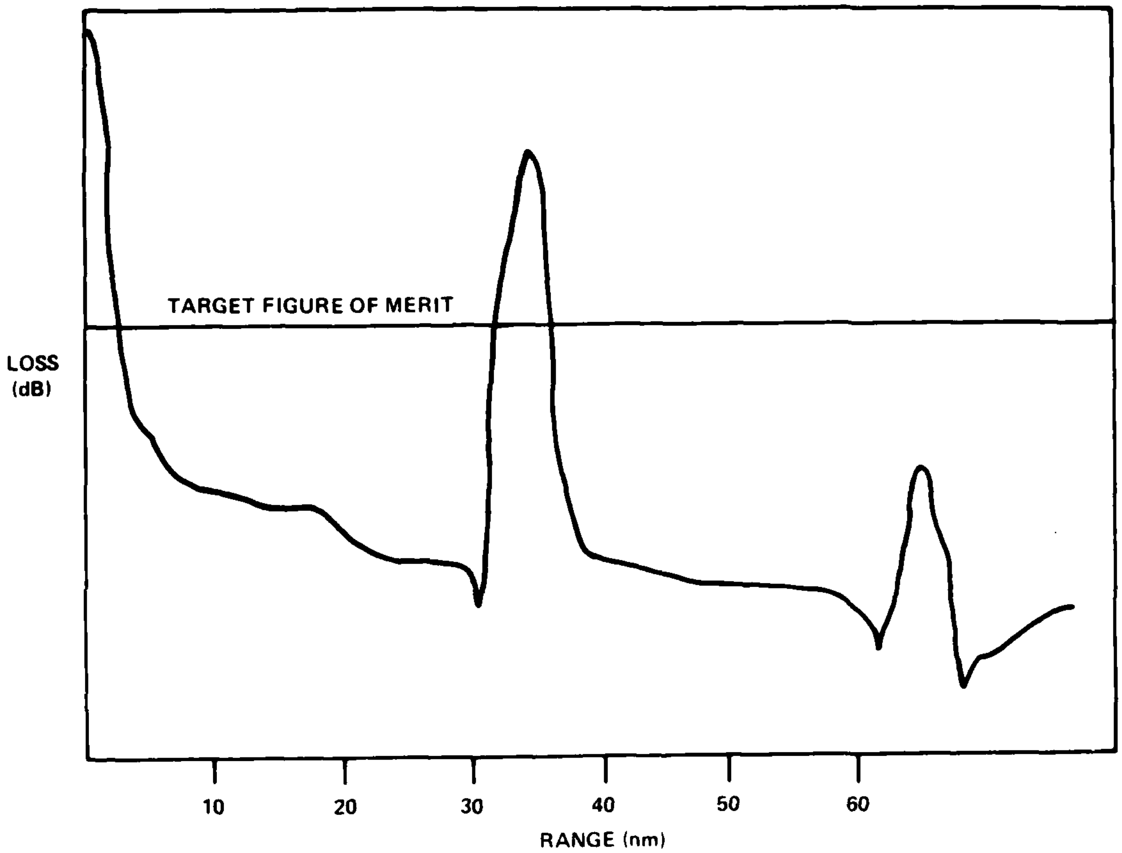

Figure A-3. Actual Environment (Variation B)

A.2.3 <u>Contingency III: Update to SPA at 1800</u>

At two hours prior to scheduled takeoff (i.e., at 1800) the ASWOC receives an updated SPA pertaining to the target of interest. This new SPA refines the initial target information. Utilizing this new SPA information, the ASWOC officer dead reckons (DRs) the target's position for the aircraft on-station time, generates a rectangular shaped SPA (150 nm by 100 nm), and recommends the deployment of a 5-6-5 sonobuoy pattern.* This new information is provided to the aircrew prior to takeoff.

A.2.4 Contingency IV: Update to SPA at 2300

As the aircrew approaches the briefed operating area (i.e., at 2300), they are informed by the ASWOC that the target appears to have altered its course and they are therefore to investigate a different search area. This new search area consists of an ellipse with a semi-major axis of 65 nm and a semi-minor axis of 40 nm. This results in an optimum pattern being a 5-6-5 distributed field. The relationships among this SPA, that specified at 1800, that specified at 1400, and the ASW aircraft's briefed flight path are pictured in Figure A-4.

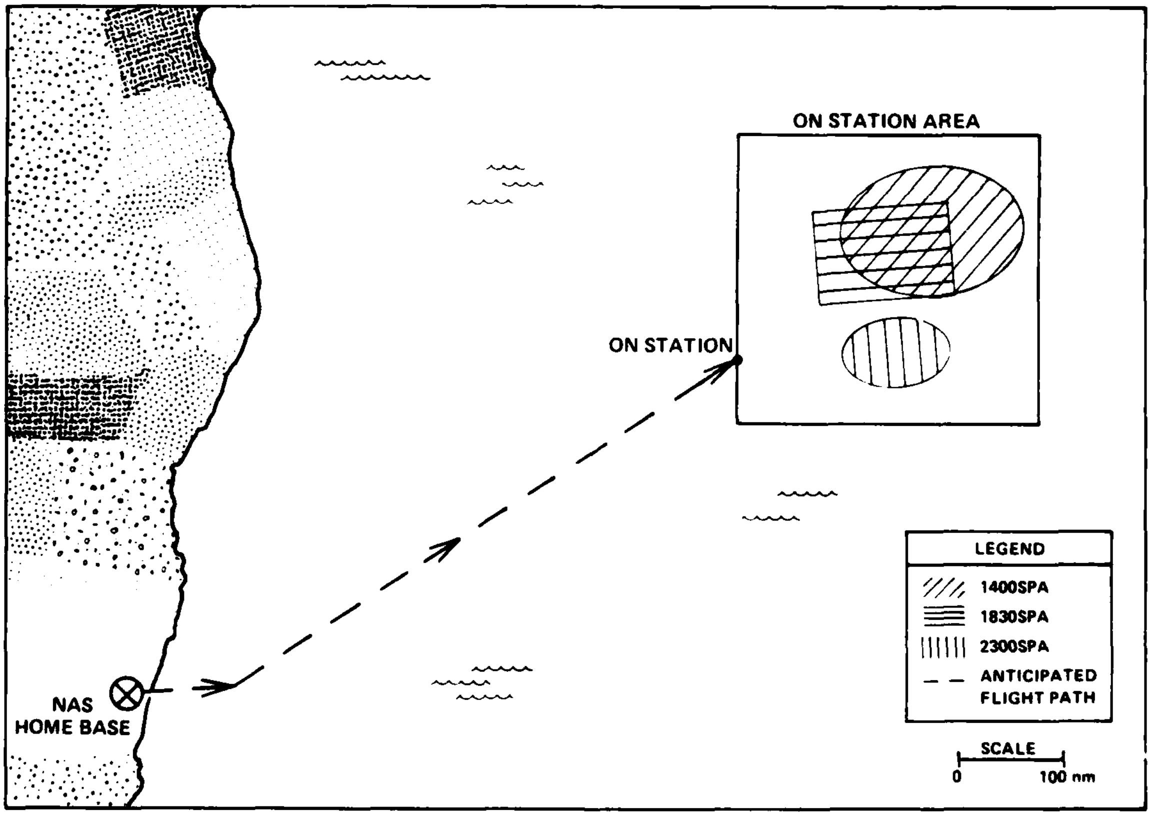

Figure A-4. Summary of SPA Locations

*Note that this pattern has been arbitrarily chosen and is not the true optimum.

A.3 CASCADING THE CONTINGENCIES TO FORM A SCENARIO TREE

From the preceeding subsections, there are a total of three possible SPAs in which the ASW aircrew may be searching (that defined 1400, 1800, or 2300), and a total of three possible environmental conditions which may be found in the search area (predicted, variation A, and variation B). These six sets of conditions can be cascaded to generate 12 possible scenarios, as shown in Figure A-5. At 1800, the predicted SPA may either be updated or not. At 2300 (regardless of whether the SPA was updated at 1800) the SPA may also be updated. Upon arriving on-station at 2330, the aircrew will determine the in-situ environmental conditions. Without regard to the SPA or its possible previous updates, they may find the predicted environmental conditions, variation A, or variation B in the search area.

If probabilities are assigned to the scenario tree according to the notation shown in Figure A-6, then the 12 scenarios would have the probabilities indicated in Table A-6. Each branch on the tree is assigned a double-subscripted probability. The first subscript refers to the temporal order of the contingency involved -- 1 indicated events at 1800, 2 indicates events at 2300, and 3 indicates events at 2330. The second subscript refers to the alternatives realized at that point in time. At 1800 and 2300, alternative 1 refers to a failure to update the SPA and 2 refers to the receipt of updated SPA information. At 2330, alternative 1 refers to expected environmental conditions, and alternatives 2 and 3 refer to environmental variation A and B, respectively. The probabilities assigned to each leaf on this scenario tree for assessment of the Sonobuoy Pattern Planning Decision Aid are also shown in Figure A-5 and Table A-6.

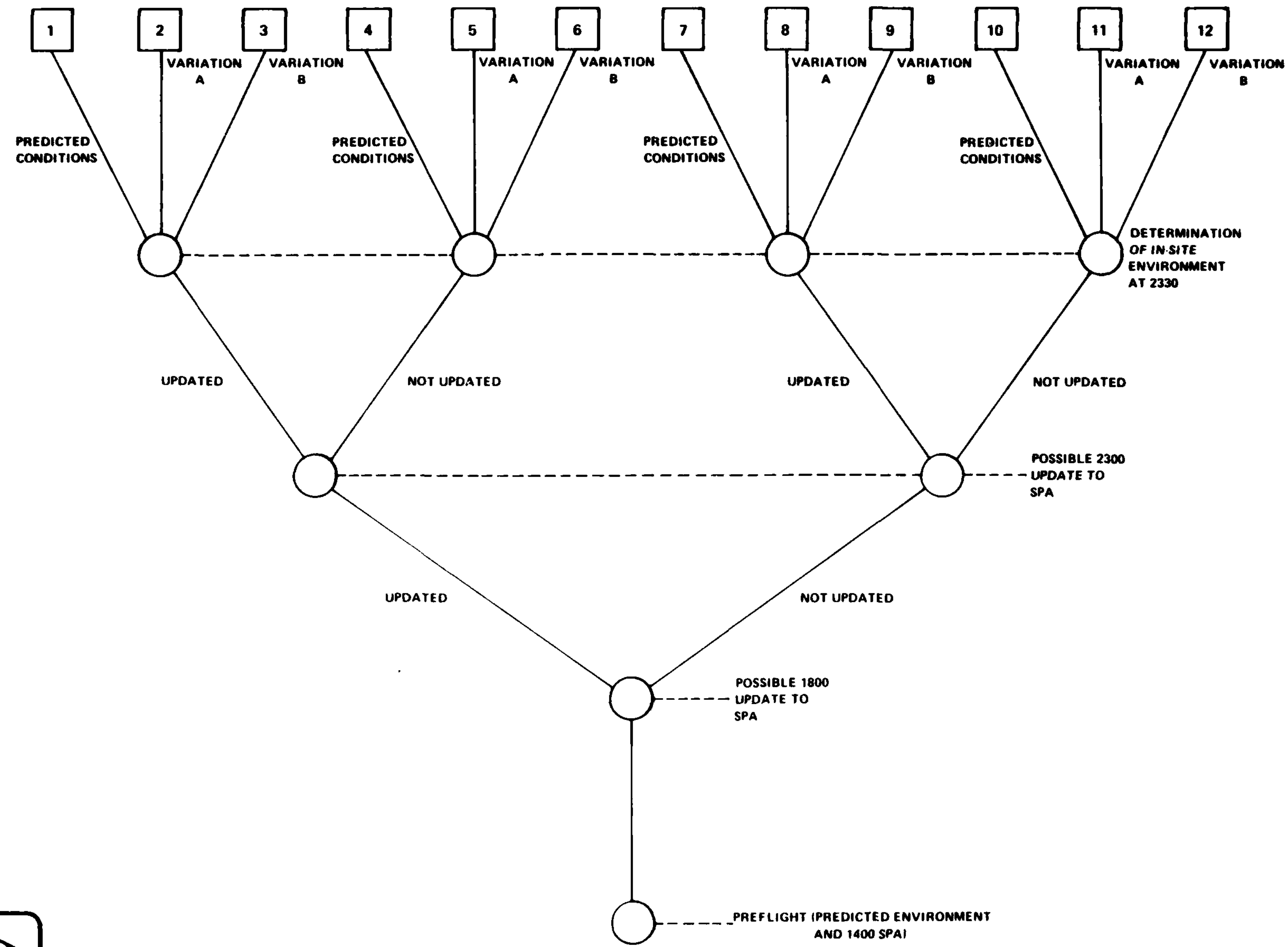

Figure A-5. Scenario-Tree Structure for Search Pattern Planning

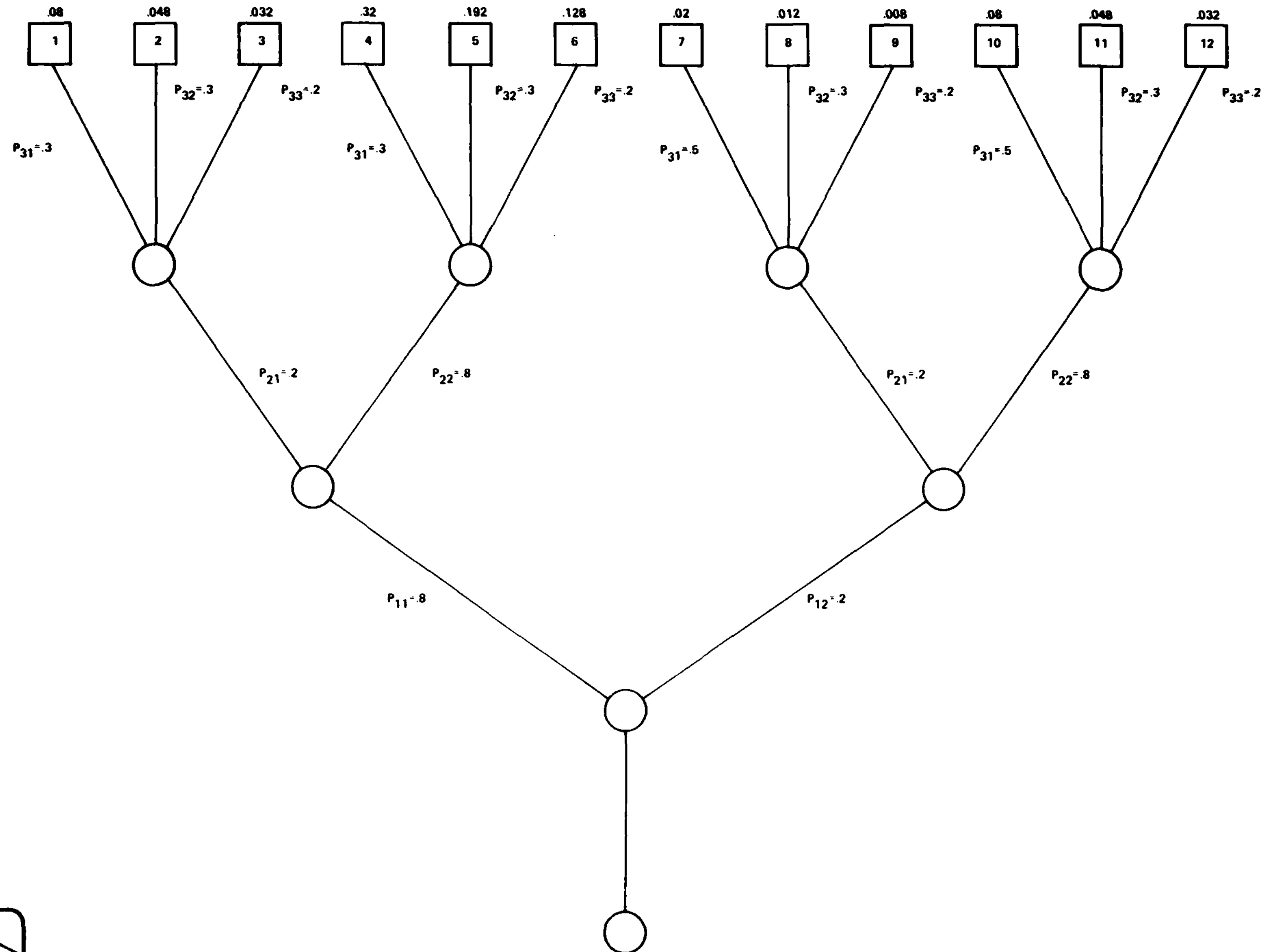

Figure A-6. Probabalistic Structure of Search Pattern Planning Scenario – Tree

Table A-6. Probability of Leaves in Search Pattern Planning Scenario Tree

SCENARIO	PROBABILITY FORMULA	ACTUAL PROBABILITIES USED
1	$P_{11}P_{21}P_{31}$	.8x.2x.5
2	$P_{11}P_{21}P_{32}$	.8x.2x.3
3	$P_{11}P_{21}P_{33}$	.8x.2x.2
4	$P_{11}P_{22}P_{31}$	.8x.8x.5
5	$P_{11}P_{22}P_{32}$	.8x.8x.3
6	$P_{11}P_{22}P_{33}$	.8x.8x.2
7	$P_{12}P_{21}P_{31}$	.2x.2x.5
8	$P_{12}P_{21}P_{32}$	.2x.2x.3
9	$P_{12}P_{21}P_{33}$	.2x.2x.2
10	$P_{12}P_{22}P_{31}$	.2x.8x.5
11	$P_{12}P_{22}P_{32}$	.2x.8x.2
12	$P_{12}P_{22}P_{33}$	.2x.8x.2

APPENDIX B
SCENARIO TREE FOR ATTACK PLANNING

B. SCENARIO TREE FOR ATTACK PLANNING

This appendix presents the scenario used in assessing the design of the Attack Planning decision aid. Subsection B.1 discusses the relationship between this scenario and that described in Appendix A for assessing the Sonobuoy Pattern Planning decision aid. Subsection B.2 outlines the general features of this scenario. Subsection B.3 describes the specific attack-planning contingencies which give rise to different evolutions of this scenario, and Subsection B.4 presents the results of combining the various contingencies into a single attack-planning scenario tree.

B.1 BACKGROUND AND RELATIONSHIP TO SONOBUOY PATTERN PLANNING SCENARIO

In assessing the Attack Planning decision aid, all factors pertaining to the aircraft sensors and environment are the same as those described in Appendix A. The environmental conditions are those defined in Appendix A as "predicted" conditions (Figure A-1). Thus, the mission involved in this scenario can be seen as simply a continuation of that outlined in Appendix A. Since the Attack Planning decision aid is to be used in the same scenario as the Search Pattern Planning decision aid, the sonobuoy inventory available for the attack planning phase is necessarily less than that available during the on-station search mission phase considered in Appendix A. The precise number of available sonobuoys is an important contingency which affects attack planning and is discussed in Subsection B.3.1. At a minimum, one 16 sonobuoy search pattern is deployed to gain initial contact, and 20 LOFAR/DIFAR sonobuoys are used to convert from convergence zone contact to direct path contact, the point at which the attack planning phase begins. Thus, the aircrew has at most 20 passive sonobuoys at the start of the attack planning phase of the mission.

B.2 BASIC SCENARIO FEATURES

The aircrew arrives on-station at the designated time (2330) and proceeds to the search area. Transit to the search area requires 30 to 45 minutes depending upon the location of the search area in relationship to the on-station ingress location. Upon obtainment of the search area, approximately 10 to 15 minutes are required to deploy the oceanographic (BT and AN) sonobuoys, obtain the results (and input the data into the decision aid in the aided condition), and select the appropriate search pattern. Time to deploy the sonobuoys within the search pattern depends upon the size and shape of the pattern, and can vary between 45 minutes and 1-1/2 hours. From this point, the scenario may evolve along different lines according to the various contingencies defined in Section B.3. Given this, the remainder of this section concerns the basic nature of the attack planning process, and the procedures and tactics which are relevant to it.

The objective of the attack planning phase is to reduce the uncertainty in the target's area/course/speed/depth from that associated with initial direct path contact to that sufficient to satify fleet-defined attack criteria for any specific weapon type. Improvement in the knowledge of the target's location, sourse, speed, and depth is gained primarily by deployment of a series of sonobuoy patterns. Each of the patterns is intended to narrow the uncertainties in the area/course/speed/depth ultimately to the degree required for weapon deployment.

The attainment of a direct path contact with a target initiates the attack planning phase of the mission. Various sonobuoy patterns/tactics (with the possible assistance of MAD tactics) are utilized in this phase to obtain attack criteria. Multiple sonobuoy patterns may be used to refine the target location to the degree of localization required for an attack. These sonobuoy patterns can consist of passive sonobuoys alone, active sonobuoys alone, or a combination of passive and active sonobuoys. The MAD tactics are limited to only those tactics used in conjunction with sonobuoy patters; unsupplemented MAD search tactics are not considered for use in this scenario.

Although the placement of an attack is the primary objective of the attack planning phase, time remaining on-station may not permit the attainment of attack criteria. At the end of its mission, the aircraft may have a relief aircraft scheduled which can continue the ASW prosecution of the target. The availability of this relief platform must be considered in the attack planning process. It is ideal to release the weapon with a high probability of kill (P_k), and if the present aircraft cannot sufficiently localize the target within the time remaining on-station, it may be advantageous to have the releif aircraft complete the localization and place the attack. However, if no relief is forthcoming, it may be ncessary to place an attack with a suboptimal P_k rather than lose the target.

The typical tactical evolution of a prosecution from direct path contact to attack criteria consists of a circular pattern followed by a series of wedge or line patterns. The initial circular pattern is intended to obtain approximate data on the target such as the quadrant in which its heading lies, an interval in which its speed lies, and an estimate of its depth in relationship to the sonic layer (above or below) for future sonobuoy hydrophone depth settings. As the attack planning phase continues, the estimates of the course/speed/depth of the target become refined enough to utilize the line, and then the wedge, patterns.

Early in the attack planning mission phase, the primary need for the course/speed/dept information is to aid in the deployment of future sonobuoys. The target course is required to allow the sonobuoy patterns to be deployed in the proper location relative to the target's movement. Target speed data is required to ensure that additional patterns are placed in the proper relationship to the target to ensure obtainment of contact at the time of target penetration of the pattern. Target depth data is needed to ensure that sonobuoy hydrophone depths are set to the same sonic layer relationship as the target. When at least one attack criterion is gained, all three factors regarding the target must then be considered in selecting a weapon, setting, and deployment location.

Prior to attainment of attack criteria, passive sonobuoy patterns should be positioned in such a manner as to maximize contact with the target. The placement of the pattern is dependent upon the pattern type, but in general the pattern should be deployed so that target penetrates it within a reasonably brief amount of time. Other considerations in pattern placement include the amount of time required to deploy the pattern, the target's speed, and the pattern's coverage area. The entire pattern should be deployed and operable prior to its penetration by the target. A time allocation for redeployment of inoperable sonobuoys should be made if at all possible.

The TACCO may at any time discontinue passive prosecution and commence active sonobuoy prosecution. Active sonobuoys provide accurate target range information. Active presecution, however, has some disadvantages over passive prosecution. In particular, passive prosecution is not as likely to alert the target to the aircraft's presence in the area. On the other hand passive prosecution can require much more time to obtain attack criteria than active prosecution. Therefore, the TACCO may decide to jeopardize the covert (passive) prosecution in order to expedite the attack process by deployment of active sonobuoys.

B.3 ATTACK PLANNING MISSION CONTINGENCIES

There are large number of contingencies which may affect the evolution of a mission from the point of direct path contact, but to keep the complexity of the scenario tree to a minimum, only three types are considered here. These are:

- The remaining on-station time once direct path contact is obtained,
- The number of passive sonobuoys available during the attack planning phase of the mission, and
- the presence/absence of a relief platform.

Each of these is discussed below in greater detail.

B.3.1 <u>Time Available for Attack Planning: Contingencies I and II</u>

The ASW aircraft arrives on-station at 2330 and begins deployment of its initial search pattern shortly thereafter (around 0030). However, initial contact with the submarine can be obtained anytime between the deployment of the of the first sonobuoy and the expiration of the last deployed sonobuoy in the pattern (a range of three hours). Once contact has been gained on a sonobuoy, approximately 40 to 60 minutes are required to convert from convergence zone to direct path contact. Not all contacts gained in the initial search pattern are convergence-zone contacts, but the probability of initially gaining a direct path contact is considerably less than that of intitially gaining a convergence-zone contact.

This 40-60 minutes does not include time initially needed to identify and classify the contact. Identification and clasification of the target are accomplished by the acoustic sensor operators and must be performed every time a different sonobuoy gains contact. However, only the initial contact classification requires an additional time allotment in this scenario. All subsequent classification times are included in the time required to convert from convergence zone to direct path contact. This is because the amount of time spent on identification and classification diminishes for subsequent sonobuoys gaining contact. Initial identification and classification is estimated to require 10-20 minutes.

Table B-1 summarizes the range of times available for the attack planning mission phase and shows that the aircrew can have between 45 and 135 minutes for performance of localization and attack tactics. This time spread assumes that initial contact may be gained at any time between the full deployment of the initial search pattern and the expiration of the last buoy in the initial search pattern. Although any point in the range of possible times for localization is equally likely, it is assumed for this scenario that direct contact is gained at either end of this range, i.e, at either

Table B-1. Range of Times Available for Attack Planning

EVENT	MINIMUM TIME	MAXIMUM TIME
Arrive in search area	30 minutes	40 minutes
Deploy BT/AN, compute pattern	10 minutes	15 minutes
Deploy Search Pattern	45 minutes	90 minutes
CZ to direct path	40 minutes	60 minutes
Identify/classify contact	10 minutes	20 minutes
TOTAL	115 minutes	225 minutes
TIME ARRIVE ON-STATION	2330	2330
Time required to direct path	135 minutes	225 minutes
Time to begin attack planning	0145	0315
OFF-STATION TIME	0400 hours	0400 hours
Time remaining for localization and attack	135 minutes	45 minutes

0145 or 0315. Thus, in Contingency I, the ASW aircraft has two hours and 15 minutes available for attack planning, while in Contingency II, it has only 45 minutes.

B.3.2 Relief Platform Availability: Contingencies III and IV

During an actual wartime situation (as would be present if use of ASW weapons were planned), there would be a general tendency to continue presecution of any target until it was destroyed. This suggests that in scenarios involving the use of the Attack Planning decision aid the presence of a relief platform should always be assumed, but there are several factors which indicate that the availability of a relief platform could be less than a certainty. Foremost among these are problems of equipment and crew availability. The airwing could simply find that it has more missions to be flown than it has aircraft and/or aircrews available. This could result in an ASW aircraft being sent on a mission such as that described in this scenario without any possibility of a relief at the end of its on-station time.

The presence or absence of a relief platform affects the way in which the TACCO directs the prosecution of the target. If a relief platform is expected, the TACCO would likely choose to hand the target off to the relief platform rather than place a sub-optimal attack that would increase the submarine's chances of escaping. On the other hand, if no hand-off platform is expected, the TACCO might be more inclined to place a sub-optimal attack on the submarine rather than place none at all. The presence/absence of a relief aircraft is thus an important factor in the tactical development of the situation. For these reasons, the second two contingencies in the attack planning scenario involve the possibility of a relief platform. In Contingency III, there is no relief platform to which the aircraft can hand off its contact, while in Contingency IV there is a relief platform due at the end of the ASW aircraft's on-station period.

B.3.3 Low Sonobuoy Stores: Contingency V

It was stated above that the ASW aircraft may have up to 20 sonobuoys remaining at the start of the attack planning phase of the mission. However, there are many possible contingencies which could cause there to be significantly fewer than this number available. For example, the ASW aircraft could deploy an initial search pattern, make contact, and proceed with localization for some time, but then lose contact with the target. If the contact is lost for a substantial period, it might be necessary to go back to more general search procedures again, and this could require use of a substantial additional number of sonobuoys. It is also possible that there could also be a higher than normal percentage of inoperative sonobuoys on the aircraft, so that many more buoys would have to be deployed to get the minimal number of operable sonobuoys in the water. And in some wartime situations, it might be necessary for the ASW aircraft to take off with less than a full complement of sonobuoys. The availability of only a restricted number of pasive sonobuoys can severely constrain the tactics the TACCO may use in conducting the final target localization operations prior to actual attack. Therefore, it is necessary to include low sonobuoy stores as a contingency within the attack planning scenario. In Contingency V, the TACCO has remaining only eight passive sonobuoys at the time a direct path contact is gained with the hostile submarine.

B.3.4 Adequate Sonobuoy Stores: Contingency VI

Despite the discussion in the preceding subsection, in many circumstances the TACCO will have an adequate store of passive sonobuoys remaining at the time the attack planning phase commences. Thus, in Contingency VI, the TACCO has 20 passive sonobuoys remaining with which to conduct the attack planning phase of the mission.

B.4 CASCADING THE CONTINGENCIES TO CREATE A SCENARIO TREE

From the preceeding section, there are two possible amounts of time the ASW aircrew may have available for the attack planning mission phase (either 45 or 135 minutes) and two possible sonobuoy loads the aircraft may have remaining at the start of attack planning (either 8 or 20 passive buoys). Also, there may or may not be a relief platform due at the end of the aircraft's on-station period. These six contingencies can be cascaded to generate eight possible scenario evolutions, as shown in Figure B-1. The ASW aircraft arrives on-station at 2330 and deploys the initial sonobuoy pattern by 0130. The time at which it gains initial contact is not specified, but it will gain a direct path contact with the submarine at either 0145 or 0315. In either case, the aircraft may have either 20 or eight passive sonobuoys remaining with which it may begin final target localization and attack planning. Again in either case, the aircraft may have a relief platform due to which it may hand off its contact, or it may not.

If probabilities are assigned to the scenario tree according to the notation shown in Figure B-2, then the eight scenarios evolutions would have the probabilities shown at the leaf-nodes in Figure B-2. Each branch on the tree is assigned a double-subscripted probability. The first subscript refers to the temporal order of the contingency involved -- 1 indicates the attainment of a direct path contact, 2 indicates the number of passive sonobuoys available for subsequent attack planning, and 3 indicates the conditions at the end of on-station. The second subscript refers to the alternatives realized at each point in the sequence. At the time of direct path contact, 1 refers to contact at 0145 and 2 refers to contact at 0345. For the number of sonobuoys remaining, 1 refers to 20 sonobuoys available, and 2 refers to eight sonobuoys available. And for the conditions at the end of on-station, 1 refers to an expectation of no hand-off and 2 refers to an expectation of a hand-off.

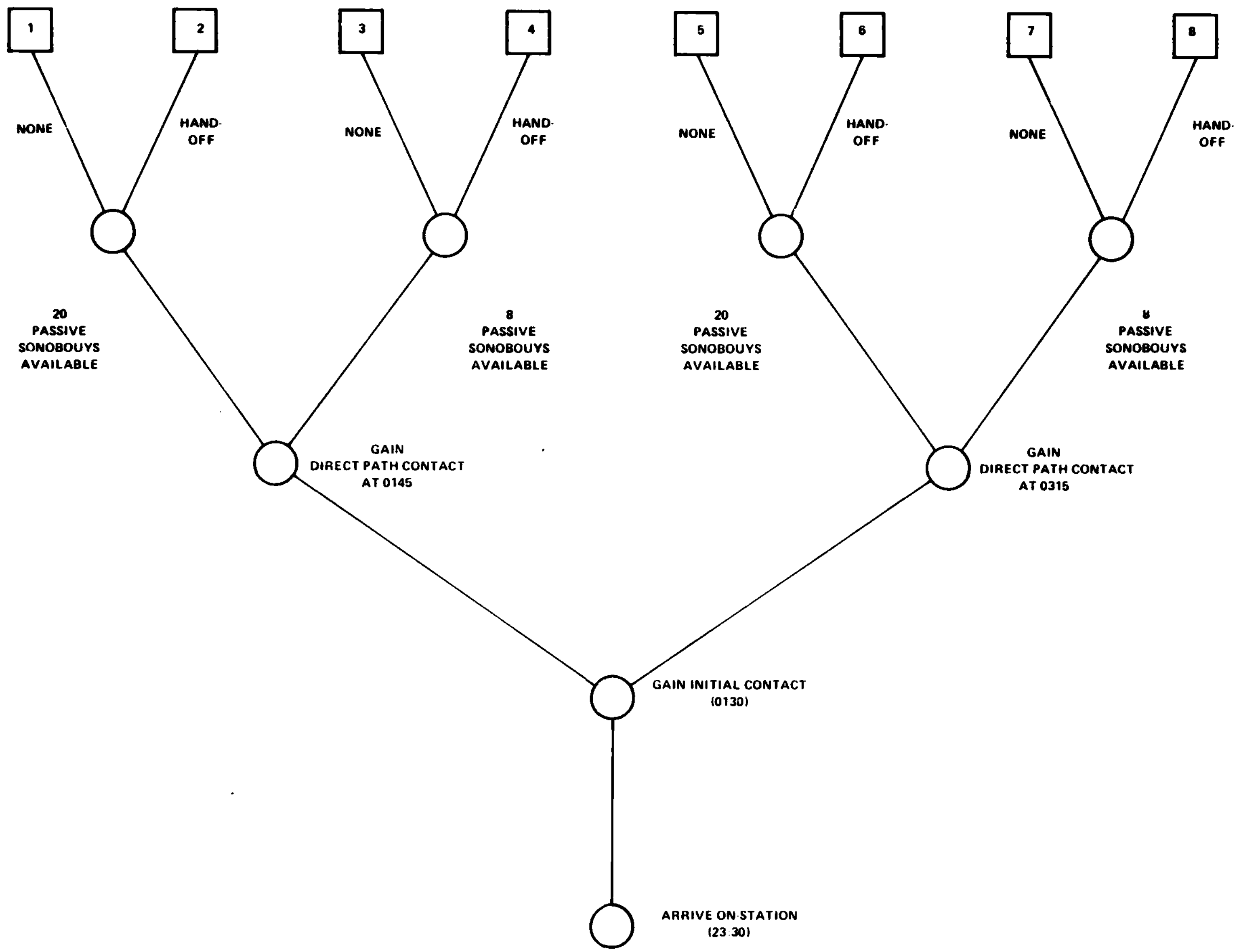

Figure B-1. Attack Planning Scenario – Tree Structure

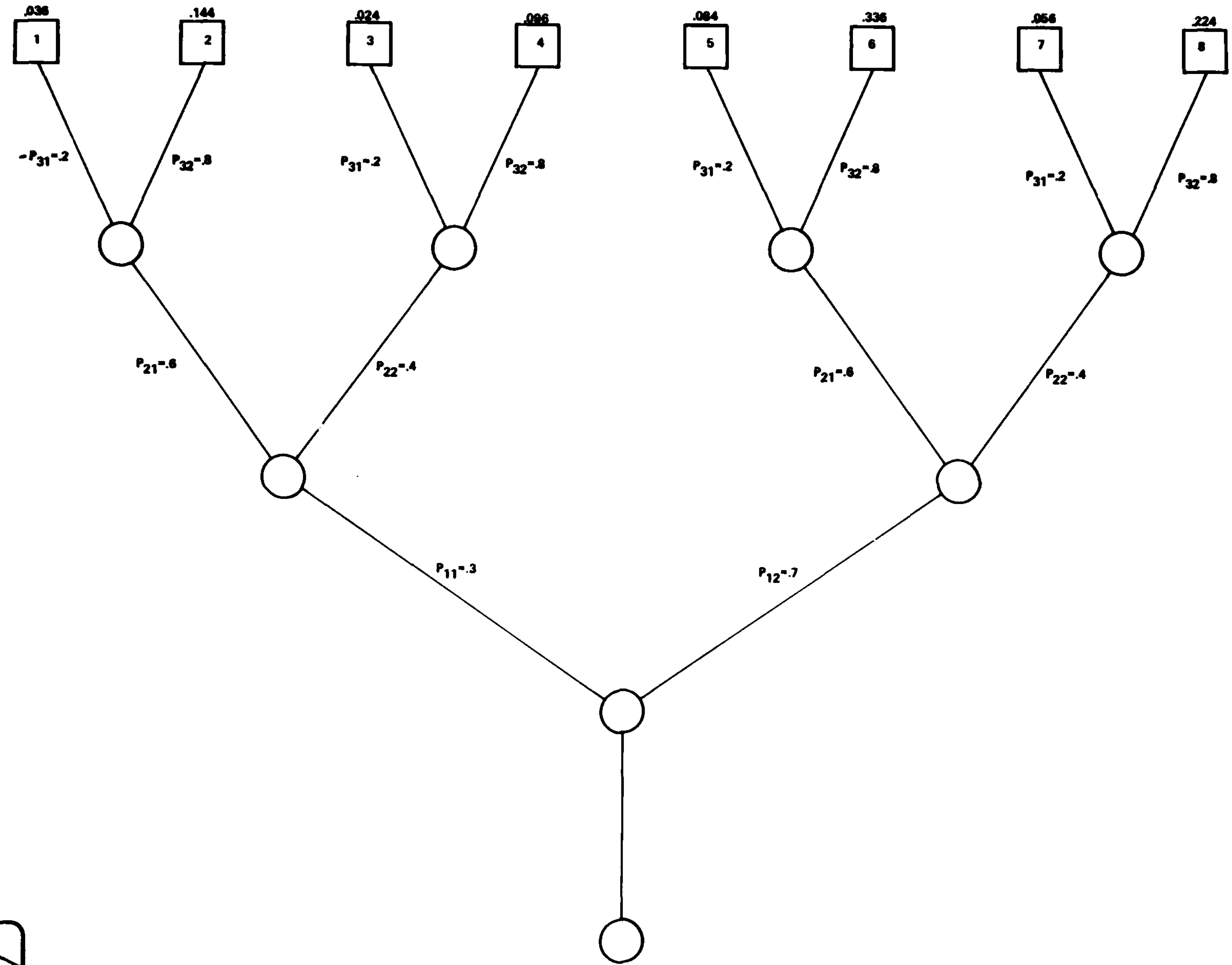

Figure B-2. Probabilistic Structure of Attack Planning Scenario Tree

APPENDIX C

HUMAN OPERATOR PROCEDURES LANGUAGE (HOPROC) REPRESENTATIONS OF TACCO TASKS IN SEARCH PATTERN PLANNING

C. HOPROC REPRESENTATIONS OF TACCO TASKS IN SEARCH PATTERN PLANNING

C.1 FOUR GROUPS OF SEARCH PATTERN PLANNING SCENARIOS

This appendix summarizes the development of the HOPROC representations of aided and unaided TACCO tasks for the search pattern planning phase of the Air ASW mission. These are the representations to which the workload measures were applied to assess the operator workload reduction benefit of the Sonobuoy Pattern Planning decision aid.

The nature of the scenario tree used (see Appendix A) has resulted in some duplication of operator procedures among the 12 "leaves" in the scenario tree. Figure A-6 depicted 12 possible evolutions of the search planning phase of the ASW mission which affect the Sonobuoy Pattern Planning process. The 12 different scenario evolutions arise from the interplay of contingencies involving updated submarine probability areas (SPAs) and differences between predicted and actual environmental conditions. Prior to arriving on-station, updated SPA data may or may not be received (independently) at 1830 and/or at 2200. This results in four possible sequences of operator actions in the enroute period. Once on-station, one of three different environmental conditions (predicted, variation A, or variation B) may be encountered. When these three on-station alternatives are combined with the four enroute sequences, 12 potential scenarios result.

There are, however, sufficient commonalities among these 12 scenarios that only four distinct time/tasklines need be constructed, based solely on the SPA update contingencies. This is because operator tasks are indentical across the three environmental variations. Thus, four groups of scenarios arise, such that only one distinct time/taskline need be developed for each. These groups are denoted A, B, C, and D and are depicted in Figure C-1.

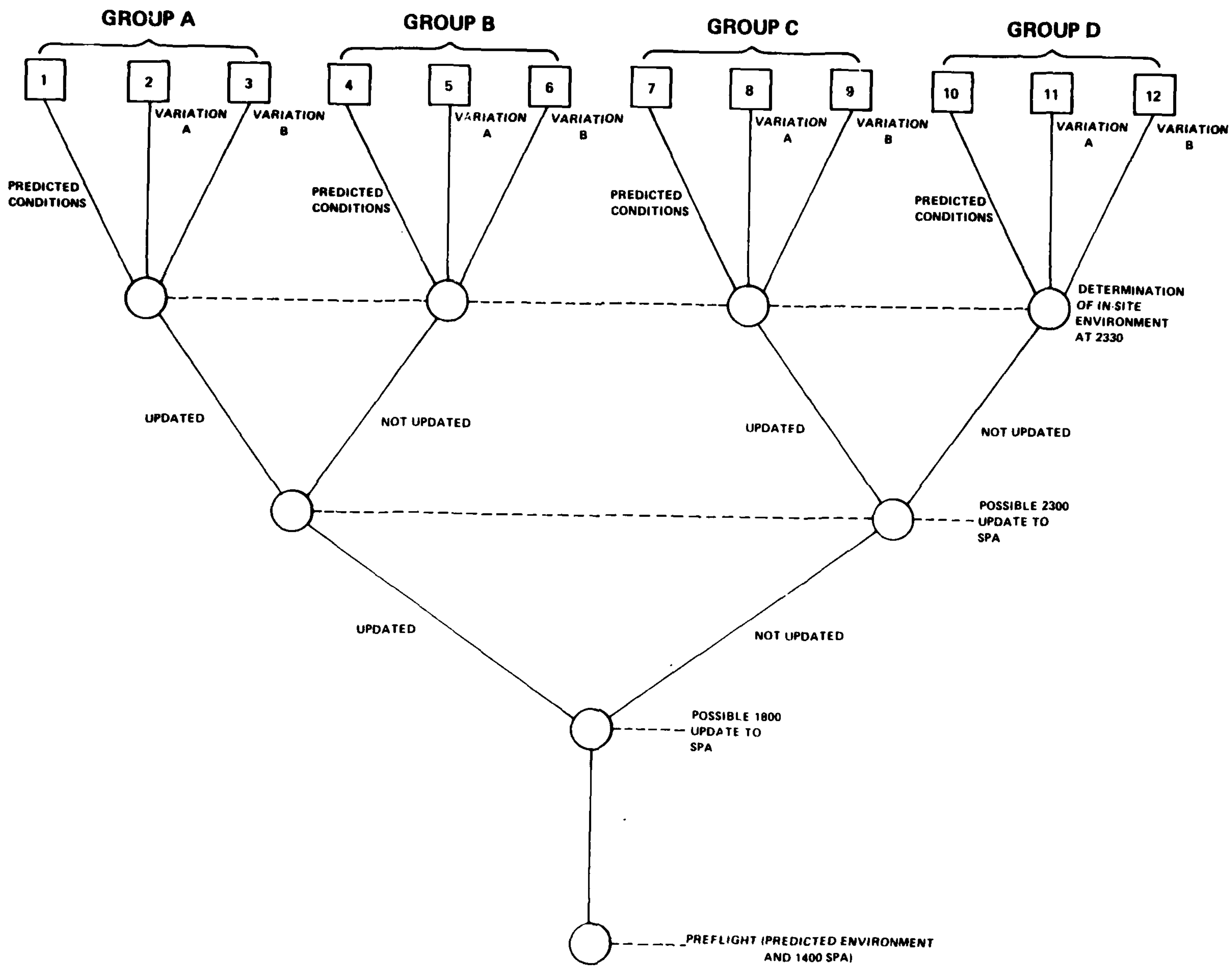

Figure C-1. Division of Search Pattern Planning Scenario into Four Groups

The formalized pidgin-HOPROC representations of TACCO tasks in each scenario group were needed for the assessment of workload reduction benefits of the Sonobuoy Pattern Planning decision aid. These representations were constructed in a two-step procedure. First, timelines were constructed indicating the functions the TACCO would perform in each scenario group and the times within the mission at which these functions would be performed. Second, the generalized pidgin-HOPROC representations of TACCO Search Pattern Planning functions (as given in Zaklad, 1981) were combined with these timelines to produce the precise temporal sequences of TACCO tasks necessary to perform the functions on each timeline. Operator workload measures were then applied directly to the four pidgin-HOPROC task sequences. The timelines of TACCO functions for the four groups of scenarios are presented in Subsection C.2. The HOPROC task sequences are presented in Subsection C.3.

C.2 TACCO FUNCTION TIME-LINES FOR FOUR GROUPS OF SCENARIOS

C.2.1 Timeline for TACCO Procedures with Two SPA Updates (Scenarios in Group A)

TACCO procedures for search planning in the scenarios in Group A consist of imposing constraints, entering two SPA updates, verifying on-station, obtaining the search area, deploying oceanographic buoys and reviewing and processing their data, and preparing and deploying the initial search pattern sonobuoys. During this period, the TACCO receives both the 1800 and the 2300 SPA updates. For the aided condition, each updated SPA is entered into the decision aid upon its receipt. For the unaided condition, the TACCO displays the new SPAs and removes the previous SPAs from the MDD. All other tasks (i.e. other than those associated with SPA updates) performed are identical in all four groups. Table C-1 presents the time-line of TACCO functions in group A scenarios.

Table C-1. TACCO Timeline for Group A Scenarios

TIME	FUNCTION	INFORMATION INVOLVED
PREFLIGHT		
1750	Process Constraints	Sonobuoy Type SSQ-41
1800	SPA Change	Rectangle: 33-10N; 34-50N; 33-10N; 34-50N; 103-07W; 104-25W; 104-25W; 103-07W
ENROUTE		
2030	Process 1800 SPA Change	
2300	SPA Change	Ellipse: 32-10N; Semi-major 60nm; Semi-minor 36nm; 103-48W orientation 085°T
2305	Delete 1800 SPA (unaided only)	
2310	Process 2300 SPA Change	
ONSTATION		
2330	Verify Onstation	31-43N; 106-23W
0002	Search Area Obtain	32-10N; 104-22W
0005	Oceanobuoy Deploy	SSQ-36 - channel 14, SSQ-87 - channel 18, chute D-5
0010	Review Results BT&AN	
0014	Enter BT Results (aided only)	
0019	Enter Ambient Noise (unaided only)	Freq 1-65, Freq 2-73, Freq 3-75, Freq 4-62, Freq 5-48
0024	Consult Decision Aid (aided only)	
0029	Prepare Aircraft to Deploy Pattern (unaided only)	
0032	Deploy Sonobuoys	

C.2.2 Timeline for TACCO Procedures with only 1800 SPA Update (Scenarios in Group B)

TACCO procedures in the scenarios in Group B differ from those in Group A only in that exactly one SPA update (at 1800) is received. In the aided condition this update is utilized to determine the initial sonobuoy patterns, spacing and orientation. Since the scenarios in Group B do not have a SPA updated at 2300, those procedures in Table 1 which involve entry of the 2300 SPA update do not apply to the TACCO procedures for this group of scenarios. Table C-2 summarizes the timeline of TACCO functions in the Group B scenarios.

C.2.3 Timeline for Procedures with only 2300 SPA Updates (Scenarios in Group C)

TACCO procedures for those scenarios in Group C TACCO differ from those in Group A only in that exactly one SPA update (at 2300) is received. In the aided condition, the 2300 SPA is used to determine sonobuoy patern and spacing. Table C-3 summarizes the timeline of TACCO functions in the scenarios in Group C.

C.2.4 Timeline for Procedures with No SPA Updates (Scenarios in Group D)

TACCO procedures for those scenarios in Group D differ from those in Group A only in that the TACCO receives no updated SPA information. Therefore, the Group D cases use the SPA information provided at the briefing to determine the initial search pattern sonobuoy locations. Table C-4 summarizes the timeline of TACCO functions in the scenarios in Group D.

C.3 TRANSFORMING TIMELINES TO TASKLINES

The generalized timelines shown in Tables C-1 through C-4 indicate the sequences in which the TACCO performs his various functions in each of the four groups shown in Figure C-1. They also show the times at which these functions are performed. These timelines were combined with the pidgin-HOPROC representations of each of the functions (as given in Zaklad, 1981) to construct timed

Table C-2. TACCO Timeline for Group B Scenarios

MISSION PHASE	TIME	FUNCTION	INFORMATION INVOLVED
PREFLIGHT			
	1750	Process Constraints	Sonobuoy Type SSQ-41
	1800	SPA Change	Rectangle: 33-10N; 34-50N; 33-10N; 34-50N; 103-07W; 104-25W
ENROUTE			
	2030	Process 1800 SPA Change	
ONSTATION			
	2330	Verify Onstation	31-43N; 106-23W
	0002	Search Area Obtain	32-10N; 104-22W
	0005	Oceanobuoy Deploy	SSQ-36 - channel 14, SSQ-87 - channel 18, chute D-5
	0010	Review Results BT&AN	
	0015	Enter BT Results (aided only)	
	0019	Enter Ambient Noise (aided only)	Freq 1-65, Freq 2-73, Freq 3-75, Freq 4-62, Freq 5-48
	0024	Consult Decision Aid (aided only)	
	0029	Prepare Aircraft to Deploy Pattern (unaided only)	
	0032	Deploy Sonobuoys	

Table C-3. TACCO Timeline for Group C Scenarios

TIME	FUNCTION	INFORMATION INVOLVED
PREFLIGHT		
1750	Process Constraints	Sonobuoy Type SSQ-41
ENROUTE		
2030	Process 1400 SPA	Ellipse: 32-40N; 103-45W, Semi-major 100nm; Semi-minor 75nm; orientation 085°T
2300	SPA Change	Ellipse: 32-10N; Semi-major 60nm; Semi-minor 36nm; 103-48W orientation 085°T
2305	Delete 1400 SPA (unaided only)	
2310	Process 2300 SPA	
ONSTATION		
2330	Verify Onstation	31-43N; 106-23W
0002	Search Area Obtain	32-10N; 104-22W
0005	Oceanobuoy Deploy	SSQ-36 - channel 14, SSQ-87 - channel 18, chute D-5
0010	Review Results BT&AN	
0015	Enter BT Results (aided only)	
0019	Enter Ambient Noise (aided only)	Freq 1-65, Freq 2-73, Freq 3-75, Freq 4-62, Freq 5-48
0024	Consult Decision Aid (aided only)	
0029	Prepare Aircraft to Deploy Pattern (unaided only)	
0032	Deploy Sonobuoys	

Table C-4. TACCO Timeline for Group D Scenarios

TIME	FUNCTION	INFORMATION INVOLVED
PREFLIGHT		
1750	Process Constraints	Sonobuoy Type SSQ-41
ENROUTE		
2030	Process 1400 SPA	
ONSTATION		
2330	Verify Onstation	31-43N; 106-23W
0002	Search Area Obtain	32-10N; 104-22W
0005	Oceanobuoy Deploy	SSQ-36 - channel 14, SSQ-87 - channel 18, chute D-5
0010	Review Results BT&AN	
0015	Enter BT Results (aided only)	
0019	Enter Ambient Noise (aided only)	Freq 1-65, Freq 2-73, Freq 3-75, Freq 4-62, Freq 5-48
0024	Consult Decision Aid (aided only)	
0029	Prepare Aircraft to Deploy Pattern (unaided only)	
0032	Deploy Sonobuoys	

sequences of HOPROC statements representing the TACCO tasks in each group of scenarios. In the following subsections, the sequences of pidgin-HOPROC statements representing the functions listed in Tables C-1 through C-4 are presented, for both the aided condition (in Subsection C.3.1) and the unaided condition (in Subsection C.3.2). Thus, to create a taskline for a given scenario group, the HOPROC sequences as given in Subsections C.3.1 and C.3.2 are combined in the order indicated by the timeline table assocated with that group of scenarios(either Table C-1, C-2, C-3, or C-4).

It should be noted in Subsection C.3.1 that any procedure which begins with the statement

Depress SEARCH-PATTERN switch

involves the use of one or more portions of the Search Pattern Planning decision aid. The procedure CONSULT-DECISION-AID describes the tasks involved with obtaining recommended search patterns from the aid, while all other procedures involving use of the decision aid merely describe the tasks involved with providing the aid with its necessary inputs. It should also be noted that any HOPROC statement which contains all capital letters and is underlined (e.g., KEYSET-SELECT) is a reference to a highly general "global" TACCO function. These global functions are discussed in Zaklad (1981).

C.3.1 HOPROC Sequences for Aided Search Pattern Planning

1750 Procedure OP-Pref

Depress SEARCH-PATTERN switch

Read Cue ('info to be updated' ...... from MDD)

KEYSET-SELECT using Update-Item (from multiple sources)

(Update-Item = op pref = D4)

Read Cue ('info to be updated' .... from MDD)

KEYSET-SELECT using Update-Item (determined previously)

(Update-Item = op pref = D2)

Read Cue ('TACCO Preference' ... from MDD)

KEYSET-SELECT using Preference (from brief sheet)

(Preference = buoy type = D2)

Read Cue ('buoy type' ... from MDD)

KEYSET-SELECT using Buoy Type (from brief sheet)

(Buoy Type = SSQ-41 = D1)

Read Cue ('TACCO Preference' ... from MDD)

KEYSET-SELECT using Preference (from brief sheet)

(Preference = none= D4)

Read Cue ('info to be updated' .... from MDD)

KEYSET-SELECT using Update-Item (using multiple sources)

(Update-Item = none = D4)

Read Cue ('info to be updated' ... from MDD)

KEYSET-SELECT using Update-Item (determined previously)

(Update-Item = none = D3)

2030 Procedure SPA-Change

Depress SEARCH-PATTERN switch

Read Cue ('info to be updated' ... from MDD)

KEYSET-SELECT using Update-Item (from TTY)

(Update-Item = SPA = D4)

Read Cue ('info to be updated' ... from MDD)

<u>KEYSET-SELECT</u> using Update-Item (determined previously)

(Update-Item = SPA = D1)

Read Cue ('define SPA shape' ... from TTY)

<u>KEYSET-SELECT</u> using SPA Shape (from TTY)

(SPA-shape = rectangle = D3)

Read Cue ('enter coordinates' ... from MDD)

<u>KEYSET-ENTER</u> using lat,long (from TTY)

Read MDD (SPA displayed)

Read Cue ('info to be updated' ... from MDD)

<u>KEYSET-SELECT</u> using Update-Item (from multiple sources)

(Update-Item = none = D4)

Read Cue ('info to be updated' ... from MDD)

<u>KEYSET-SELECT</u> using Update-Item (determined previously)

(Update-Item = none = D3)

2310 Procedure SPA-Change

Depress SEARCH-PATTERN switch

Read Cue ('info to be updated' ... from MDD)

<u>KEYSET-SELECT</u> using Update-Item (from TTY)

(Update-Item = SPA = D4)

Read Cue ('info to be updated' ... from MDD)

<u>KEYSET-SELECT</u> using Update-Item (determined previously)

(Update-Item = SPA = D1)

Read Cue ('define SPA shape' ... from MDD)

KEYSET-SELECT using SPA Shape (from TTY)

(SPA-Shape = ellipse = D1)

Read Cue ('location' ... from MDD)

KEYSET-ENTER using lat,long (from TTY)

Read MDD ('Semi-Major ... from MDD)

KEYSET-ENTER using Semi-Major (from ITTY)

Read Cue ('Semi-Minor' ... from MDD)

KEYSET-ENTER using Semi-Minor (from TTY)

Read Cue ('orientation' ... from MDD)

KEYSET-ENTER using Orientation (from TTY)

Read MDD (SPA displayed)

Read Cue ('info to be updated' ... from MDD)

KEYSET-SELECT using Update-Item (from multiple sources)

(Update-Item = none = D4)

Read Cue ('info to be updated' ... from MDD)

KEYSET-SELECT using Update-Item (determined previously)

(Update-Item = none = D3)

End.

2330 Procedure Verify-On-Station

START: DISPLAY-NAMED-TABLEAU using Nav-Parameters

Read ETA, dist-to-go, etc. (from Nav-Parameters)

DISPLAY-NAMED-TABLEAU using Flight Plan

Read ETA, dist-to-go, lat,long of P1 (from Flight Plan)

Read lat,long of On-Station (from brief sheet)

Determine If-On-Station (compare lat,longs of On-Station and P1)

Recall ETA and dist-to-go. (from tableaus)

Execute Procedure FTP-CAPTURED

CHECK-MDD

End.

0002 Procedure Search-Area-Obtain

DISPLAY-NAMED-TABLEAU using Flight-Plan

Read ETA, dist-to-go, lat,long of P1 (from Flight Plan)

Determine if Search-Area-Obtained

(compare lat,long of P1 to lat,long of search area) (from brief sheet)

HOOK-VERIFY using Ocean-Buoy-Drop Lat,Long (point of search area origin)

SELECT-EXP-FTP

CHECK-MDD

DISPLAY-NAMED-TABLEAU using Nav-Parameters

Read lat,long of A/C (from Nav-Parameters)

End.

0005 Procedure Ocean-Buoy-Select

DISPLAY-NAMED-TABLEAU using Stores-Management

Read AN-Buoy-Bin (from Stores-Management)

SONO-SELECT using AN-Buoy-Bin (from Stores-Management)

Depress SELECT-BT switch (M-34)

DISPLAY-NAMED-TABLEAU using Nav-Parameters

Read A/C lat,long (from Nav-Parameters)

CHECK-MDD

Comm-with-operator (message: prepare ASQ-36 and ASP for recording)

End.

0010 Procedure Review-Oceanobuoy-Results

Determine BT-Predicted Differences (from NAV/COMM and SS1 operators)

(read brief sheet and compare actual BT conditions

with predicted BT data)

Document BT-Predicted Differences (documented on brief sheet)

Determine if Sono-Depth-Mods-Req'd (from NAV/COMM and SS1 operators)

(read brief sheet and compare actual layer depth with predicted

layer depth)

Document Sono-Depth-Mods-Req'd (on debrief sheet)

(Determine AN-Results)

WHILE (less-than-5-frequencies-recorded)

DO:

Set AN switch to frequency ordinal

Read AN-METER (frequency results displayed)

End WHILE.

End.

0014 Procedure Enter-BT-Results

Depress SEARCH-PATTERN switch

Read Cue ('info to be updated' ...... from MDD)

KEYSET-SELECT using Update-Item (determined from multiple sources)

(Update-Item = BT = D1)

Read Cue ('enter surface temp' .... from MDD)

KEYSET-ENTER using Surface-Temp (from NAV/COMM and SS1 operators)

Read Cue ('enter layer depth, temp' ... from MDD)

KEYSET-ENTER using Layer Depth, Temp (from NAV/COMM and SS1 operators)

Read Cue ('depth, temp every 100 ft. and anomalies' ..... from MDD)

KEYSET-ENTER using Depth, Temp (every 100 ft. and anomalies)

(from NAV/COMM and SS1 operators)

Read Cue ('info to be updated' ...... from MDD)

KEYSET-ENTER using Update-Item (determined from multiple sources)

(Update-Item = other = D4)

Read Cue ('info to be updated' ...... from MDD)

KEYSET-SELECT using Update-Item (determined from multiple sources)

(Update-Item = none = D3)

End.

0019 Procedure Enter-AN-Results

Depress SEARCH-PATTERN switch

Read Cue ('info to be updated' ...... from MDD)

KEYSET-SELECT using Update-Item (from multiple sources)

(Update-Item = Ambient = D2)

Read Cue ('enter AN' .... from MDD)

KEYSET-ENTER using AN-Frequencies (from debrief sheet)

Read Cue ('info to be updated' ...... from MDD)

KEYSET-ENTER using Update-Item (from multiple sources)

(Update-Item = none = D4)

Read Cue ('info to be updated' ...... from MDD)

KEYSET-SELECT using Update-Item (determined previously)

(Update-Item = none = D3)

End.

0024 Procedure Consult-Decision-Aid

Depress SEARCH-PATTERN Switch

Read Cue ('Item to be updated'.......from MDD)

KEYSET-SELECT using Update-Item (determined from multiple sources)

(Update-item-search-pattern=D4)

WHILE (any-pattern-restrictions-need-modifying)

DO:

> Read Cue ('Item to be updated'.......from MDD)
>
> KEYSET-SELECT using Update-Item (from multiple sources)
>
> desired-item = patterns-considered = D1
> spacing-limits = D2
> orientation-limits = D3
> number-buoys-used = D4
>
> Read Display ('Current restrictions'.......from MDD)
>
> Read Cue ('Enter new values'.......from MDD)
>
> KEYSET-ENTER using desired new values

End WHILE.

Read Cue ('Item to be updated'.......from MDD)

KEYSET-SELECT using Update-item (from multiple sources)

(desired-item=none=D5)

Read Cue ('Item to be updated'.......from MDD)

KEYSET-SELECT using Update-item (from multiple sources)

(Update-item=none=D3)

Depress RECOMMENDED-PATTERNS Switch

Read patterns-Recommended Display (from MDD)

Evaluate recommended patterns and select desired search pattern

Read Cue ('Enter Pattern Selected'.......from MDD)

KEYSET-ENTER using selected pattern

End.

0029 Procedure Deploy Sonobuoy

While (any-sonobuoy-not-deployed)

Do:

Determine Sonobuoy Desired (LOFAR from brief sheet)

Depress LOFAR switch (M-26)

Read Cue ('select life, depth'... from MDD)

KEYSET-ENTER using Life, Depth desired.

End WHILE.

0032 Procedure Launch-Buoy

WHILE (any-buoys-are-not-launched)

DO:

DISPLAY-NAMED-TABLEAU using Nav-Parameters.

Read ETA, dist-to-go (from brief sheet)

Determine FTP-CAPTURED

Read MDD (buoy symbol displayed)

End WHILE.

C.3.2 HOPROC Sequences for Unaided Search Pattern Planning Functions

1750 Procedure Document-Constraints

Document Desired-Constraint on debrief sheet (Sonobuoy Type SSQ-41)

End.

2030 Procedure Display-SPA

Depress GEO-NAV switch

Depress INSERT-LAT-LONG switch

Read Cue ('insert lat,long'... from MDD)

While (any known corner is not-marked)

DO:

KEYSET-ENTER using Lat,Long (one corner,from brief sheet)

HOOK-VERIFY using Lat,Long (one corner,from MDD)

Depress REFERENCE-MARK switch

End WHILE.

HOOK-VERIFY using Lat,Long (one corner, from MDD)

Depress LINE-DISPLAY switch

Depress CURSOR switch

WHILE (number-of-lines-marked is less than 4)

DO:

More Cursor-Position to Referenced-Marked-Position. (from MDD)

(manipulate trackball from point of origin to reference marks

resulting in 2 perpendicular lines.)

Depress MARK switch

IF (number-of-lines-marked equals 2)

Then

HOOK-VERIFY using Lat,Long (opposite corner,from MDD)

Else

End IF.

End WHILE.

2305 Procedure Destroy-SPA

WHILE (Any Old-SPA-Points are visible (on MDD))

DO:

DESTROY-PT-DATA using Old-SPA-Point.

End WHILE.

2310 Procedure Display-SPA

Depress GEO-NAV switch

Depress INSERT-LAT-LONG switch

Read Cue ('Insert lat,long'... from MDD)

KEYSET-ENTER using Lat,Long (from brief sheet)

HOOK-VERIFY using Lat,Long (from brief sheet)

Depress LINE-DISPLAY switch

Depress CURSOR switch

WHILE (any semi-major axis is unmarked)

DO:

More Cursor - Position to Semi-Major-Position. (from brief sheet)

(read cursor readout to confirm position)

Depress REFERENCE-MARK switch

End WHILE.

WHILE (any semi-minor axis is unmarked)

DO:

More Cursor-Position to Semi-Minor Position. (from brief sheet)

(read cursor readout to confirm position)

Depress REFERENCE-MARK switch

End WHILE.

Read MDD (SPA displayed)

End.

2330 Procedure Verify On-Station (same as aided)

0002 Procedure Search-Area-Obtain (same as aided)

0005 Procedure Ocean-Buoy-Select (same as aided)

0010 Procedure Review-Oceanobuoy-Results (same as aided)

0024 Procedure Deploy-Buoy (same as aided)

0032 Procedure Launch-Buoy (same as aided)

APPENDIX D

ATTACK PLANNING MISSION ACHIEVEMENT MODEL

D. ATTACK PLANNING MISSION ACHIEVEMENT MODEL

This appendix describes the computer program used to model mission achievement during the Attack Planning segment of the Air ASW mission. The program is designed to operate interactively with a keyboard operator performing the functions of a TACCO.

D.1 SUMMARY OF PROGRAM OPERATION

During operation of the program, the individual acting as TACCO controls the deployment and monitoring of two types of passive sonobuoys and one type of active sonobuoy to search for a hostile submarine whose movements are unknown to him except through the data provided by the sonobuoys. The TACCO also controls the deployment of torpedoes against the submarine. Until the TACCO decides to deploy an active sonobuoy or until the supply of passive sonobuoys is depleted, the program remains in the passive prosecution mode. In this mode, the TACCO may at any time choose to deploy either of two types of passive sonobuoys (directional, non-directional) at some specific location. Alternatively, he may simply monitor the already-deployed sonobuoys for any period of time. In the passive mode, the program provides minute-by-minute detection information and for directional sonobuoys bearing information as well.

When the simulated aircraft's supply of passive sonobuoys is exhausted, or at any time at the TACCO's discretion, the program enters the active prosecution mode. Once active mode has been entered, the user may not return to the passive mode. In active mode, the TACCO's choices are as follows:

- He may deploy an active sonobuoy at a specified location,
- He may ping any of the already-deployed sonobuoys at a specified time,

- He may deploy a torpedo at a specified location, or
- He may exit the program.

If all active sonobuoys have been deployed, the TACCO can continue to ping any of the active sonobuoys until he decides to exit the program, or until he destroys the submarine. When the TACCO pings a sonobuoy, he receives a message stating whether a detection resulted, and the range at which the detection occurred.

After the program ends, whether at the operator's discretion or upon the destruction of the submarine, the TACCO receives summary data outlining the submarine's unalerted movements during the simulated mission so that the scenario can be reconstructed for later analysis.

D.2 PROGRAM COMPONENTS

The program consists of two submarine motion models, three sonobuoy models, a torpedo model, and an interactive interface. The following subsections describe the features of each of these models. It should be noted that the assumptions utilized in building each model were made in consultation with ASW operational analysts.

D.2.1 Submarine Motion Models

D.2.1.1 Submarine Movement Model I: Unalerted Motion. This model is employed to determine the hostile submarine's movements while the program is running in the passive prosecution mode. At this time, the submarine is unaware of the presence of the ASW platform and thus is operating under normal transit conditions. The submarine location is represented as a point in an x-y plane (which represents the ocean surface), with a depth indicator which may be either 1 (placing the submarine is above the sonic layer), or 2 (placing it below the sonic layer). The size of the submarine is so much smaller than the ocean distances encountered in the scenario that actual dimensions of the submarine can be ignored. It should be noted that the submarine depth indicator identifies the thermal layer in which the submarine is traveling, not its actual depth. Since thermal layers are not of constant depth with respect to (x,y) position, a depth indicator change by the submarine (from 1 to 2 or 2 to 1) occurs when either the submarine changes depth or when the submarine crosses a thermal layer. In this motion model, submarine depth changes are instantaneous and distributed in time as a Poisson random variable with a mean of 20 minutes.

Submarine movement in the x-y plane is at a constant speed (normally 12 knots) and exhibits a semi-random zig-zag pattern about a definite heading, specified as a program parameter. All turns are made instantaneously, as the differences in path length and submarine position, when compared to a more realistic turning model, are inconsequential. To generate the zig-zag pattern, the following algorithm was developed. If the general submarine heading is $\hat{\theta}$ degrees, the initial course for the submarine is generated as $(\theta+\alpha)$ where α is a uniform random variable with range +30° to -30°. All subsequent angles of travel are then calculated as normal random variables with an appropriate standard deviation and a mean equal to the negative of the previous angle of travel (i.e., $\theta-\alpha$). Thus, each direction change tends to bring the submarine back toward its general heading. The time spent traveling on each heading thus generated is calculated as a normal random variable with mean and standard deviation of 20 and 8 minutes respectively. This algorithm produces a realistic set of movements for a submarine operating under normal (unalerted) conditions.

D.2.1.2 <u>Submarine Movement Model II: Alerted Motion</u>. When the simulation enters the active mode, (i.e., when an active sonobuoy is deployed), the submarine position must be known at any time (not just minute-by-minute as in the unalerted model) because the TACCO may decide to ping an active sonobuoy at any time. Therefore, a more detailed description of the submarine's movement is necessary for the active mode of program operation. To provide the needed accuracy, the alerted model has the submarine perform all turns in a circular path and make all depth changes in a continuous motion.

More importantly, once the ASW aircraft deploys and pings the first active sonobuoy, the submarine becomes alerted to the presence (and presumably the intention) of the ASW aircraft. This is because it can detect the signal emitted by the active sonobuoy, even at distances substantially greater than those at which the sonobuoy can detect it. Thus, once the submarine knows it is being prosecuted by the ASW aircraft, it commences evasive maneuvers to avoid being destroyed. The alerted model features evasive tactics on the part of the submarine, which it employs as soon as it is alerted to the ASW aircraft's presence i.e., when it detects a ping from an active sonobuoy. For purposes of this simulation, it is assumed that the submarine can detect a ping whenever the range between the submarine and the active sonobuoy is less than or equal to 1.5 times the active sonobuoy detection range. If a *single* active sonobuoy is detected by the submarine, the submarine turns 180° off the bearing to the sonobuoy. If the submarine detects two active sonobuoys, it turns away from the sonobuoys along the perpendicular bisector of the line drawn between them. In either case, the submarine alters its depth to gain a cross-layer situation and *may* change its speed to maximum while attempting to escape from the active sonobuoy pattern.

The submarine heads away from the active sonobuoy for at least 10 minutes after hearing the last active sonobuoy ping. It then alters its heading to resume an intercept course with the convoy. It resumes the intercept heading by making a 90° heading change (from whatever its course was at the time) and travel 5 nm along the new heading before changing course to the new intercept heading. The submarine then resumes a speed of 9 knots and begin making course and depth changes as before. If the submarine detects a torpedo, it moves directly away from the torpedo at maximum speed. These tactics, as well as portions of computer code used to implement them in the program described here, were adapted from the model used in Banowetz and Iavecchia (1981).

D.2.3 SONOBUOY MODELS

The sonobuoy models used in the program simply define the regions in which a given sonobuoy detects a submarine and the kinds of information provided when a detection occurs. Detection region models for all types of sonobuoys contain a direct path contact zone; for passive sonobuoys, they also contain one or two convergence zone contact regions. All direct path contact zones are represented as a circular region centered on the sonobuoy's (x,y) location. All convergence zones are represented as annular regions, concentric with the sonobuoy's (x,y) location. Since the simulated ocean consists of two thermal layers, different detection regions are defined for same-layer detection (i.e., where the submarine and the sonobuoy are in the same thermal layer), and cross-layer detection (i.e., where they are in different thermal layers). Different detection regions are also defined for each thermal layer in which the buoy may be located. Thus, there are four sets of detection regions possible for each sonobuoy.

D.2.3.1 Omnidirectional Passive Sonobuoy Model. The omnidirectional sonobuoy will detect a submarine in any direct path contact or convergence zone region, but will not provide any bearing information on the contact. The same-layer detection region for the omnidirectional passive buoy consists of a direct path zone and two annular convergence zones whose radii and widths are set by program parameters. For cross-layer detection, contact is possible only in the direct path zone. The radius of each detection region depends on the layer in which the sonobuoy resides. When a submarine enters a region in which a detection may occur, the model prints out a message that the sonobuoy involved has received a contact.

D.2.3.2 Directional Passive Sonobuoy Model

The directional sonobuoy operates identically to the omnidirectional sonobuoy, except that it provides information on the approximate bearing of the contact along with the information that contact has occurred. Detection regions are thus defined in the same manner as in the omnidirectional passive sonobuoy model. When a detection occurs (i.e., when the submarine model moves the submarine into one of the possible detection zones for a sonobuoy of this type), the directional sonobuoy model also generates information on the bearing of the submarine with respect to the sonobuoy. This bearing information is reported in two ways. The true bearing of the submarine to the sonobuoy is reported, but because actual directional sonobuoys are not 100 percent accurate, a "reported" bearing is also generated. This reported bearing is the true bearing with a normally distributed range-dependent error term added. As the submarine moves, the true bearing continues to be generated as the true bearing of the submarine to the sonobuoy. The "reported" bearing, however, is modified by taking the previous error term and adding it to another error term whose mean and standard deviation are small numbers. Thus the reported error, once initially established, is approximately constant as the submarine moves through the detection regions for that sonobuoy.

D.2.3.3 Active Sonobuoy Model. The active sonobuoy provides information on the range of any target which lies within its detection region, but it does so only when pinged by the TACCO. The detection region of an active sonobuoy is represented by a direct path zone only, whose radius depends on the layers in which the sonobuoy and submarine are located.

When the TACCO requests a ping of an active sonobuoy, the model determines if a detection occurred, and provides range-to-target information if it did. The range information includes a normally-distributed range-dependent error.

D.2.4 Torpedo Model

When the TACCO believes that he has localized the target submarine to within fleet-specified attack criteria, he can instruct the program to deploy a weapon (torpedo) against the submarine. The model used to represent torpedo effectiveness is a segmented "cookie-cutter" model. A "circle of effectiveness" for the torpedo is defined as a circular area with radius equal to the torpedo's maximum effectiveness range. This circle is centered at the submarine's location at the time of torpedo deployment. If the torpedo is deployed outside this circle, the weapon has a zero probability of kill (or P_k). However, although all area outside the circle has uniform P_k, all area within the circle does not. The area within the circle is divided into 12 regions, defined by first drawing two circles within the maximum effectiveness circle and then dividing the circle into quadrants defined by two perpendicular diameters. The resulting division of the circle is depicted in Figure D-1.

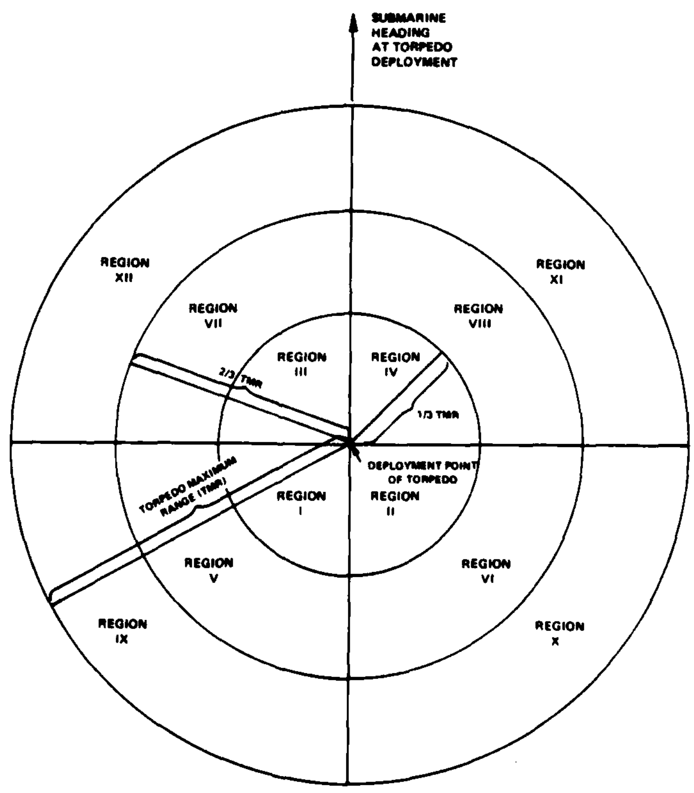

Figure D-1. Division of Effective Torpedo Area into Twelve Regions

When a torpedo is deployed, the torpedo model first determines whether it was dropped within the maximum effectiveness circle. If not, it reports the P_k as 0. If the weapon was deployed within the circle, then the model determines the region of the circle in which its was dropped and reports the submarine's P_k as the P_k value associated with that region of the circle. If the P_k is greater then .5, the model assumes the submarine has been destroyed and stops the simulation. The torpedo model does not consider the submarine depth or acoustical propagation conditions.

D.3 PROGRAM PARAMETERS

Most aspects of this program are parameter-driven. Prior to compilation of the program, the user supplies values for the program parameters to reflect the characteristics of the specific scenario being simulated. The program parameters can be broken into five groups:

- ASW aircraft parameters,
- Target submarine parameters,
- Sonobuoy parameters,
- Weapon parameters, and
- Environmental parameters.

All parameters of each type are listed in Table D-1. In each application of the program, specific values for these parameters were taken from the information contained in the scenario descriptions given in Appendices A and B.

D.4 USER INTERFACE

The program operates interactively with an operator who receives its output and relays it to the individual acting as TACCO, and who supplies

Table D-1. Program Parameters

PARAMETER TYPE	PARAMETER NAME	PARAMETER MEANING
ASW Platform	N	Number of passive buoys carried by aircraft.
	NUMBUOY	Number of active buoys carried by aircraft.
Target Submarine	ADEV	Standard deviation of Gaussian deviation of next submarine course change from value of ALPHAD.
	ALPHAD	Overall heading of submarine (set at beginning run or at compile time).
	AMAX	Maximum deviation of any course from ALPHAD value.
	SUBMAX	Maximum evasive speed of submarine during active prosecution mode of program (measured in knots).
	SUBNORS	Normal operating speed of submarine during active prosecution mode of program (measured in knots).
	TDEV	Standard deviation of time to be spent traveling on next heading.
	TMAX	Maximum time to be spent traveling on any unalerted heading.
	TMEAN	Mean time to be spent traveling on next unalerted heading.
	TMIN	Minimum time to be spent traveling on any unalerted heading.
	U1	Submarine speed during passive prosecution protion mode of program (measured in knots).
Sonobuoy	DIFF	Difference a submarine detected by a directional passive sonobuoy must travel before error in reported range information is adjusted.
	SIGMAP	Standard deviation of error in reported bearing information (for directional passive sonobuoys) calculated at moment of initial detection.
	SIGMAS	Standard deviation of error correction in reported bearing information (for directional passive sonobuoys) when submarine travels distance of value of DIFF after initial detection or last correction to reported bearing information.
Weapon	TRI	Maximum effective range of torpedo.
	PROBTAB(I)	Probability of kill of submarine in Region I within effective range of weapon (see Figure E-1).
Environment	ACRD	Cross-layer detection range for active sonobuoys when sonobuoy is in deep layer.
	ACRS	Cross-layer detection range for active sonobuoys when sonobuoy is in shallow layer.
	ACTMDRC	Cross-layer range for submarine to detect active sonobuoy which is pinging.

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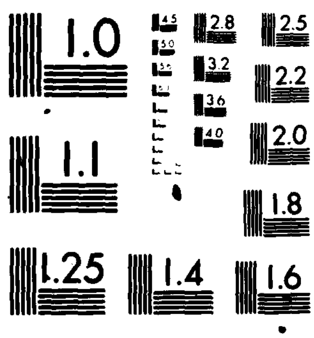

MICROCOPY RESOLUTION TEST CHART
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Table D-1. Program Parameters (continued)

PARAMETER TYPE	PARAMETER NAME	PARAMETER MEANING
Environment	ACTMDRS	Cross-layer range for submarine to detect active sonobuoy which is pinging.
	ARD	Same-layer detection range for passive sonobuoys when sonobuoy is in deep layer.
	ARS	Same-layer detection range for passive sonobuoys when sonobuoy is in shallow water.
	DEPLA	Depth in feet below which submarine is in the deep thermal layer.
	P1	Radius of direct path connect zone for passive sonobuoys in deep thermal layer.
	P2	Inner radius of first convergence zone for passive sonobvuoys in deep thermal layer.
	P3	Outer radius of first convergence zone for passive sonobuoys in deep thermal layer.
	P4	Inner radius of second convergence zone for passive sonobuoys in deep thermal layer.
	P5	Outer radius of second convergence zone for passive sonobuoys in deep thermal layer.
	PC1	Radius of cross-layer direct path contact zone for passive sonobuoys in deep thermal layer.
	R1	Radius of direct path contact zone for passive sonobuoys in shallow thermal layer.
	R2	Inner radius of first convergence zone for passive sonobuoys in shallow thermal layer.
	R3	Outer radius of first convergence zone for passive sonobuoys in shallow thermal layer.
	R4	Inner radius of secon convergence zone for passive sonobuoys in shallow thermal layer.
	R5	Outer radius of second convergence zone for passive sonobuoys in shallow thermal layer.
	RC1	Radius of cross-layer direct path contact zone for passive sonobuoys in shallow thermal layer.

information provided by the individual acting as TACCO. The basic mode of communication in the interface is through natural-language-like queries and responses. A simplified interactive session is shown in Table D-2 to exemplify the various queries and responses employed in the interface. In this sample session, the operator first specifies an initial position and heading for the submarine, and a ten-digit random seed for the program's random number generator. To start, one omnidirectional passive sonobuoy is deployed at three minutes after the start of the simulation and monitored for five minutes. Then, one directional passive sonobuoy is deployed eight minutes after the start of the simulation. An active sonobuoy is deployed two minutes later and, beginning one minute after that is pinged at one-minute intervals for three minutes. Finally, a torpedo is deployed at 15 minutes after the start of the simulation. The submarine is then destroyed and the simulation ended. In Table D-2 information entered by the operator is shown in italics, while information printed by the program is shown in a standard Roman lettering.

TABLE D-2 SAMPLE INTERACTION WITH ATTACK PLANNING MISSION ACHIEVEMENT MODEL

```
ENTER SEED AS TEN DIGIT RANDOM NUMBER
? 1394802771
ENTER INITIAL SUB POSITION (X,Y,D) AND MEAN DIRECTION
? 20,10,1,39.
DO YOU WISH TO DEPLOY SONOBUOY (1=YES, 2=NO)?
? 1
ENTER O,D,A, OR T (O = OMNIDIRECTION, D = DIRECTIONAL, A = ACTIVE, T = TORPEDO)
? O
ENTER SONOBUOY 1 POSITION AND TIME (X,Y,D,T)
? 19,9.5,1,3

TIME ELAPSED = 3 MINUTES
SUB DATA: X,Y,D = 20.433     10.415     1

SONOBUOY 1 = CONTACT

DO YOU WISH TO DEPLOY SONOBUOY (1 =YES, 2 = NO)?
? 2

HOW MANY MINUTES DO YOU WISH TO MONITOR PASSIVE BUOYS?
? 5

TIME ELAPSED = 4 MINUTES
SUB DATA: X,Y,D = 20.578     10.553     1

SONOBUOY 1 = CONTACT

TIME ELAPSED = 5 MINUTES
SUB DATA: X,Y,D = 20.722     10.692     1

SONOBUOY 1 = CONTACT

TIME ELAPSED = 6 MINUTES
SUB DATA: X,Y,D = 20.867     10.83

SONOBUOY 1 = CONTACT

TIME ELAPSED = 7 MINUTES
SUB DATA: X,Y,D = 20.011     10.968     1

SONOBUOY 1 = CONTACT

TIME ELAPSED = 8 MINUTES
SUB DATA: X,Y,D = 21.256     11.106     1
```

TABLE D-2 SAMPLE INTERACTION WITH ATTACK PLANNING MISSION ACHIEVEMENT MODEL
(continued)

```
SONOBUOY 1 = CONTACT

DO YOU WISH TO DEPLOY SONOBUOY (1=YES, 2=NO)?
? 1
ENTER O,D,A OR T (O = OMNIDIRECTIONAL, D = DIRECTIONAL, A = ACTIVE, T = TORPEDO)
? D
ENTER SONOBUOY 2 POSITION, TIME (X,Y,D,T)
? 21,11.5,1,8

TIME ELAPSED = 8 MINUTES
SUB DATA: X,Y,D = 21.156     11.106     1

SONOBUOY 1 = CONTACT
SONOBUOY 2 = CONTACT TRUE BEARING = 148.36  MEASURED BEARING = 158.41

DO YOU WISH TO DEPLOY SONOBUOY (1=YES, 2=NO)?
? 2

HOW MANY MINUTES DO YOU WISH TO MONITOR PASSIVE SONOBUOYS?
? 2

TIME ELAPSED = 9 MINUTES
SUB DATA: X,Y,D = 21.300     11.245     1

SONOBUOY 1 = NO CONTACT
SONOBUOY 2 = CONTACT  TRUE BEARINGS=121.09  MEASURED BEARING = 130.02

TIME ELAPSED = 10 MINUTES
SUB DATA: X,Y,D = 21.445     11.383

SONOBUOY 1 = NO CONTACT
SONOBUOY 2 = CONTACT   TRUE BEARING      MEASURED BEARING

DO YOU WISH TO DEPLOY SONOBUOY (1 = YES, 2 = NO)?
? 1

ENTER O,D,A, OR T (O = ONMIDIRECTIONAL, D = DIRECTIONAL, A = ACTIVE, T = TORPEDO)
? A

ENTER ACTIVE BUOY 1 POSITION (X,Y,D)
? 22, 12, 1

DO YOU WISH TO PING A BUOY (1=YES, 2=NO)?
? 1

ENTER BUOY NUMBER (1 TO 1) AND TIME TO PING
? 1,11
```

TABLE D-2 SAMPLE INTERACTION WITH ATTACK PLANNING MISSION ACHIEVEMENT MODEL (continued)

TIME ELAPSED = 11 MINUTES
SUB DATA: X,Y,D = 21.515   11.570   1

ACTIVE BUOY 1: DETECTION AT RANGE 1297 YARDS

DO YOU WISH TO DEPLOY AN ACTIVE BUOY (1=YES, 2=NO, 3=TORPEDO)?
? *2*

DO YOU WISH TO PING A BUY (1=YES, 2=NO)?
? *1*

ENTER BUOY NUMBER (1 TO 1) AND TIME TO PING
? *1,12*

TIME ELAPSED = 12 MINUTES
SUB DATA: X,Y,D = 21.582   11.758   2

ACTIVE BUOY 1: DETECTION AT RANGE 966 YARDS

DO YOU WISH TO DEPLOY AN ACTIVE BUOY (1=YES, 2=NO)?
? *2*

DO YOU WISH TO PING A BUOY (1=YES, 2=NO)?
? *1*

ENTER BOUY NUMBER (1 TO 1) AND TIME TO PING
? *1,13*

TIME ELAPSED: 13 MINUTES
SUB DATA: X,Y,D = 21.341   11.769   2

ACTIVE BUOY 1: DETECTION AT RANGE 1400 YARDS

DO YOU WISH TO DEPLOY AN ACTIVE BUOY (1=YES, 2=NO, 3=TORPEDO)?
? *3*

ENTER TORPEDO DROP COORDINATES AND DEPLOY TIME (X,Y,T)
? *21,11.4,15*

TIME ELAPSED: 15 MINUTES
SUB DATA: X,Y,D = 20.769   11.928   2

TORPEDO DEPLOYED 15 MINUTES INTO SIMULATION: KILL PROBABILITY .81
TORPEDO DEPLOYED 15 MINUTES INTO SIMULATION: 474 YARDS FROM SUBMARINE

SUBMARINE DESTROYED

TABLE D-2 SAMPLE INTERACTION WITH ATTACK PLANNING MISSION ACHIEVEMENT MODEL
(continued)

```
SUMMARY OF UNALERTED SUBMARINE COURSE CORRECTIONS

 TIME     ANGLE     X       Y
 25.8      43.7   2372    1357

SUMMARY OF UNALERTED SUBMARINE DEPTH CHANGES

            NONE

STOP
```

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